

**Climate change, climate variability and adaptation  
options in smallholder cropping systems of the  
Sudano - Sahel region in West Africa**

**Bouba Traore**

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**Climate change, climate variability and adaptation  
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Sudano - Sahel region in West Africa**

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**Thesis**

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*A Mah Koné, ma très chère grande mère!*



## **Abstract**

In the Sudano-Sahelian zone of West Africa (SSWA) agricultural production remains the main source of livelihood for rural communities, providing employment to more than 60 percent of the population and contributing to about 30% of gross domestic product. Smallholder agricultural production is dominated by rain-fed production of millet, sorghum and maize for food consumption and of cotton for the market. Farmers experience low and variable yields resulting in increasing uncertainty about the ability to produce the food needed for their families. Major factors contributing to such uncertainty and low productivity are climate variability, climate change and poor agricultural management. The objective of this thesis was to evaluate through experimentation, modelling and participatory approaches the real and perceived characteristics of climate variability and change and their effects on crop production in order to identify opportunities for enhancing the adaptive capacity of farmers in the Sudano - Sahelian zone.

The general approach was based on, first, understanding the past trend of climate and its effect on the yield of main crops cultivated in southern Mali; second, evaluating together with farmers different adaptation options in the field; third, evaluating climate adaptation options through experimentation on station; and fourth, evaluating the consequences of different adaptation options under different long term scenarios of climate change.

Minimum daily air temperature increased on average by 0.05°C per year during the period from 1965 to 2005 while maximum daily air temperature remained constant. Seasonal rainfall showed large inter-annual variability with no significant change over the 1965 – 2005 period. However, the total number of dry days within the growing season increased significantly indicating a change in rainfall distribution. There was a negative effect of maximum temperature, number of dry days and total seasonal rainfall on cotton yield.

Farmers perceived an increase in annual rainfall variability, an increase in the occurrence of dry spells during the rainy season, and an increase in temperature. Drought tolerant, short maturing crop varieties and appropriate planting dates were the commonly preferred adaptation strategies to deal with climate variability. Use of chemical fertilizer enhances the yield and profitability of maize while the cost of fertilizer prohibits making profit with fertilizer use on millet. Training of farmers on important aspects of weather and its variability, and especially on the onset of the rains, is critical to enhancing adaptive capacity to climate change.

A field experiment (from 2009 to 2011) indicated that for fertilized cereal crops, maize out yielded millet and sorghum by respectively 57% and 45% across the three seasons. Analysis of 40 years of weather data indicated that this finding holds for longer time periods than the length of this trial. Late planting resulted in significant yield decreases for maize, sorghum and cotton, but not for millet. However, a short duration variety of millet was better adapted for late planting. When the rainy season starts late, sorghum planting can be delayed from the beginning of June to early July without substantial reductions in grain yield. Cotton yield at early planting was 28% larger than yield at medium planting and late planting gave the lowest yield with all three varieties. For all four crops the largest stover yields were obtained with early planting and the longer planting was delayed, the less stover was produced.

Analysis of predicted future climate change on cereal production indicated that the temperature will increase over time. Generally stronger increases occur in the rcp8.5 scenario compared to the rcp4.5 scenario. The total annual rainfall is unlikely to change. By mid-century predicted maize grain yield losses were 45% and 47% with farmer's practice in the rcp4.5 and rcp8.5 scenarios respectively. The recommended fertilizer application did not offset the climate change impact but reduced the yield losses to 38% of the baseline yield with farmer's practice. For millet median yield loss was 16% and 14% with farmer's practice in the rcp4.5 and rcp8.5 scenario. If the recommended fertilizer rates are applied to millet, the predicted yield losses with farmer's practice due to climate change are reversed in both climate scenarios.

Under future climate change, food availability will be reduced for the all farm types, but that large farm will still achieve food self – sufficiency in terms of energy requirement. The medium and small farm types see a further decrease in food self-sufficiency. Addressing smallholder food self-sufficiency depends upon the capacity of each farm type to appropriately choose the planting date while taking into account the acceptable planting date window for each individual crop.

**Key words:** crop production, maize, millet, sorghum, cotton, fertilizer, rainfall, temperature, APSIM, Mali,



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## Table of contents

|                   |  |     |
|-------------------|--|-----|
| <b>Chapter 1:</b> | General introduction   | 1   |
| <b>Chapter 2:</b> | Effects of climate variability and climate change on crop production in southern Mali          | 11  |
| <b>Chapter 3:</b> | Farmer's perceptions on climate change and agricultural adaptation strategies in southern Mali | 33  |
| <b>Chapter 4:</b> | Evaluation of climate adaptation options for Sudano - Sahelian cropping systems                | 55  |
| <b>Chapter 5:</b> | Impact of future climate change on maize and millet production and adaptation options          | 81  |
| <b>Chapter 6:</b> | General discussion   | 107 |
|                   | References   | 123 |
|                   | Appendices   | 139 |
|                   | Summary (English)  | 143 |
|                   | Samenvatting (summary in Dutch)  | 147 |
|                   | Résumé (summary in French)   | 151 |
|                   | Acknowledgements   | 155 |
|                   | Curriculum vitae   | 159 |
|                   | Educational certificate of the Graduate School PE&RC   | 162 |
|                   | Funding  | 163 |

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**General introduction**

### **Problem statement**

In the Sudano-Sahelian zone of West Africa (SSWA) agricultural production remains the main source of livelihood for rural communities, providing employment to more than 60 percent of the population and contributing to about 30% of gross domestic product (FAO, 2012). Smallholder agricultural production is dominated by rain-fed production of millet, sorghum and maize for food consumption and of cotton for the market. Farmers experience low yields resulting in increasing uncertainty about being able to produce the food needed for their families (Breman and Sissoko, 1998; Drechsel et al., 2001). Major factors contributing to such uncertainty and low productivity are climate variability, poor soil fertility, poor agricultural management and climate change.

In West Africa soil fertility is inherently low (Bationo and Buerkert, 2001; Giller et al., 2011; Piéri, 1989; Vanlauwe et al., 2011) and represents the main constraint for agricultural development. This situation is aggravated by the reduction of fallow lengths, cultivation of fragile lands, limited use of inorganic fertilizer due to high world market fertilizer prices and limited access to credit (de Graaff et al., 2011; Ehui and Pender, 2005). In addition, low availability of organic fertilizers contributes to the decline in soil fertility. Land degradation including both water and wind erosion further impoverishes the soils in this region (Cleaver and Schreiber, 1994).

On top of low soil fertility, constraints related to current climate variability and future climate change affect crop yields. Indeed, since the early 1990s the Intergovernmental Panel for Climate Change (IPCC) has provided evidence of accelerated global warming and climate change. The latest IPCC's Fifth Assessment Report (AR5) presents new evidence of climate change (IPCC, 2013). The global average temperature showed a warming of 0.78 (0.72 to 0.85) °C over the period of 1850 to 2012, and current predictions for the end of the 21<sup>st</sup> century are that global average temperature increase will be between 1.5°C, and 2°C (IPCC, 2013). In Africa global warming is likely to be even larger than the global annual mean warming, and this across the whole continent and across all seasons (IPCC, 2013).

The increase would be less marked in Guinean areas and the highest increase would take place in the Western Sahelian region (FAO, 2008b). For rainfall, significantly increases have been observed in the eastern parts of North and South America, in northern Europe and in northern and central Asia, while a decrease and drying has been observed in the Sahel (IPCC,

2007b), against the background of strong multi decadal variability in rainfall (Dai and Trenberth, 2004; Le Barbé et al., 2002). In the Sahel region, wet conditions in the 1960s alternated with drier conditions in the 1970s and 1980s. Evidence of changes in rainfall at global scales is complex because of large regional differences, gaps in spatial coverage and lack of long term data. Climate predictions indicate that the contrast in rainfall between wet and dry regions and between wet and dry seasons will increase (IPCC, 2013) even though the projections of rainfall are uncertain for the West African region because of uncertainty in the quantification of potential vegetation-climate links. Different global circulation models do not agree in their predictions of climate change for the region, although results of a number of the models indicate that on average the amount of rainfall in Mali will not change, but that the inter-annual variability of the amount of rainfall will increase. Also the frequency of extreme droughts is expected to increase (Traore et al., 2007; Washington and Harrison, 2004)

Climate variability and change is a reality that is affecting rural livelihoods in West Africa today and presents a growing challenge in the region, as in many other parts of the African continent and elsewhere (Jalloh et al., 2013). Climate change will have far reaching consequences for the poor and marginalized groups of which the majority depends on agriculture for their livelihoods and have a low capacity to adapt.

Climate extremes that occurred in 1972 and 1984 demonstrated the highly variable climate conditions, and illustrated the difficulty of majority of sub Saharan smallholder to cope with extremes climate events (Cook et al., 2004; IPCC, 2001; Segele and Lamb, 2005; Washington and Preston, 2006). With projections of future climate suggesting that the continent will become drier (Desanker and Magadza, 2011; Hulme et al., 2001) and extremes more frequent (IPCC, 2007b), it is clear that climate change will cause more harm to poor countries because their people rely more heavily on natural resources which are susceptible to destruction by floods and drought that are caused by climatic changes. This, in turn is likely to negatively affect the livelihoods of the poor as well as deepen poverty (Hope, 2009).

For many countries, changes in rainfall are expected to constrain agricultural production and therefore detrimentally impact food security. An example of this might be a reduction in the growing season length or increased uncertainty in the start of the growing season. As consequence agricultural yields in some countries are projected to fall by 50% by 2020 and overall crop revenue might decrease by 90% by 2100 (Boko et al., 2007). Because of their low adaptive capacity, small-scale farmers are likely to be the worst affected by these decreases in revenue (Boko et al., 2007). Sultan et al. (2013) predicted for eight contrasting sites in the Sudano-Sahelian zone of Burkina Faso, Senegal, Mali and Niger using a process-

based crop model a negative impact on yields of millet and sorghum of up to -41% by the end century under an scenario with increased temperature and decreased rainfall. Muller (2011) and Roudier et al. (2011) predicted across West Africa crop yield decreases of up to 50% as a result of increasing temperature. Furthermore, when warming exceeds 2 °C, negative impacts caused by this temperature rise cannot be counteracted by any potential positive change in rainfall (Sultan et al., 2013).

Adaptation options based on appropriate planting dates are important for maximizing cereal grain yields because optimum planting dates favour the establishment of healthy and vigorous plants (Egharevba, 1979). Generally, planting time in the Sudano-Sahelian zone coincides with the first substantial rains of the season in order to optimize yields of both grain and straw (Egharevba, 1979). However, due to the erratic rainfall patterns, the first rain suitable for planting is often followed by several dry days that may cause the planting to fail and oblige the farmer to replant. Delayed planting can avoid this problem, but late planting results in a substantial shortening of the growing season and, consequently, in lower yields. Another constraint related to the planting date is the availability of labour, especially at the beginning of the rainy season. Lack of, or insufficient labour can hinder the capacity of the farmer to prepare the soil, thereby causing a delay in the planting date (Mohino et al., 2011).

In the smallholder farming system of southern Mali, the cropping area allocated to food crop (maize, millet and sorghum) and to cash crop (maize and cotton) vary according to farm types (Bazile and Soumare, 2004). Large and medium farm types are more cash crops oriented while small farm types are more food crops oriented. Long duration varieties mostly planted early produced more because they could make use of the longer period for grain filling (Bello et al., 2012). Short duration varieties require lower temperature sums to reach flowering earlier, are in general associated with low grain yield (Akbar et al., 2008) but can be harvested early in order to meet food shortage during the lean period (Fok et al., 2000). The choice of the variety is as important as planting date. Clear choices of varieties need to be made by the farmer depending on the start of the rainy season.

Crop management practices based on crop diversification, adjusting the planting date and choice of variety are the adaptation strategies most readily available to farmers to deal with the effects of climate variability, but quantitative information for these options is scant for the Sudano-Sahelian region. A good understanding of seasonal weather variability patterns is of critical importance.

To guide future adaptation we need an understanding of past and current climate and coping strategies, to better understand what is acceptable to farmers. This information in combination with farmers' perceptions of climate change and variability is key to prioritize measures to address and prepare for climate impact.

### **Objectives**

In this study, I assess through experimentation, modelling and participatory approaches the real and perceived characteristics of climate variability and change and their effects on crop production in order to identify opportunities for enhancing the adaptive capacity of farmers in the Sudano - Sahelian zone. The hypothesis in this study was that rain-fed agricultural production is negatively affected by climate change and variability, but that adaptation options exist to stabilize yields that are accessible, adoptable, and relevant to smallholder farmers.

### ***Specific objectives***

The specific objectives of my study are:

- a) To quantify possible changes of climate and its variability and their impact on yield of cotton, sorghum, and groundnut over 30 years in southern of Mali.
- b) To understand farmer's perceptions of climate change and agricultural adaptation strategies;
- c) To evaluate the effects of planting date on the yield of long, medium and short duration varieties of maize, millet, sorghum and cotton in southern of Mali;
- d) To quantify and evaluate the impact of climate change on crop production and the risk of crop failure under different future climatic scenario and identify climate adaptation options;

### **Study setting**

The study was performed in southern of Mali. I deliberately selected this region because while it is only 13.5% of the Malian territory, it represents 50% of the cultivable lands of the country. Smallholder agricultural production is dominated by rain-fed production of millet, sorghum and maize for family food consumption and of cotton for the market. Agriculture is the major livelihood activity for 70% of the population.

Cropping systems are characterized by low productivity due to erratic rainfall, poor soil fertility, and poor crop management with few external inputs. The capacity of these systems to support local food security depends to a large extent on the seasonal patterns of rainfall, which vary strongly between years. The agricultural sector is negatively affected by climate variability, including heat waves, droughts, floods, and other extreme weather events. A major constraint for crop production is the amount of rainfall and its intra and inter-annual variability. Seasonal rainfall amount, intra-seasonal rainfall distribution and dates of onset/cessation of the rains influence crop yields and determine the agricultural calendar. The risk of crop failure is likely to become higher considering the future climate predictions for West Africa.

Our general approach (Fig 1.1) was based on, first, understanding the past trend of climate and its effect on the yield of main crops cultivated in southern Mali; second evaluating together with farmers different adaptation options in the field; third evaluating climate adaptation options through experimentation on station; and fourth evaluating the consequences of different adaptation options under different long term scenarios of climate change.



## Chapter 1 – General introduction

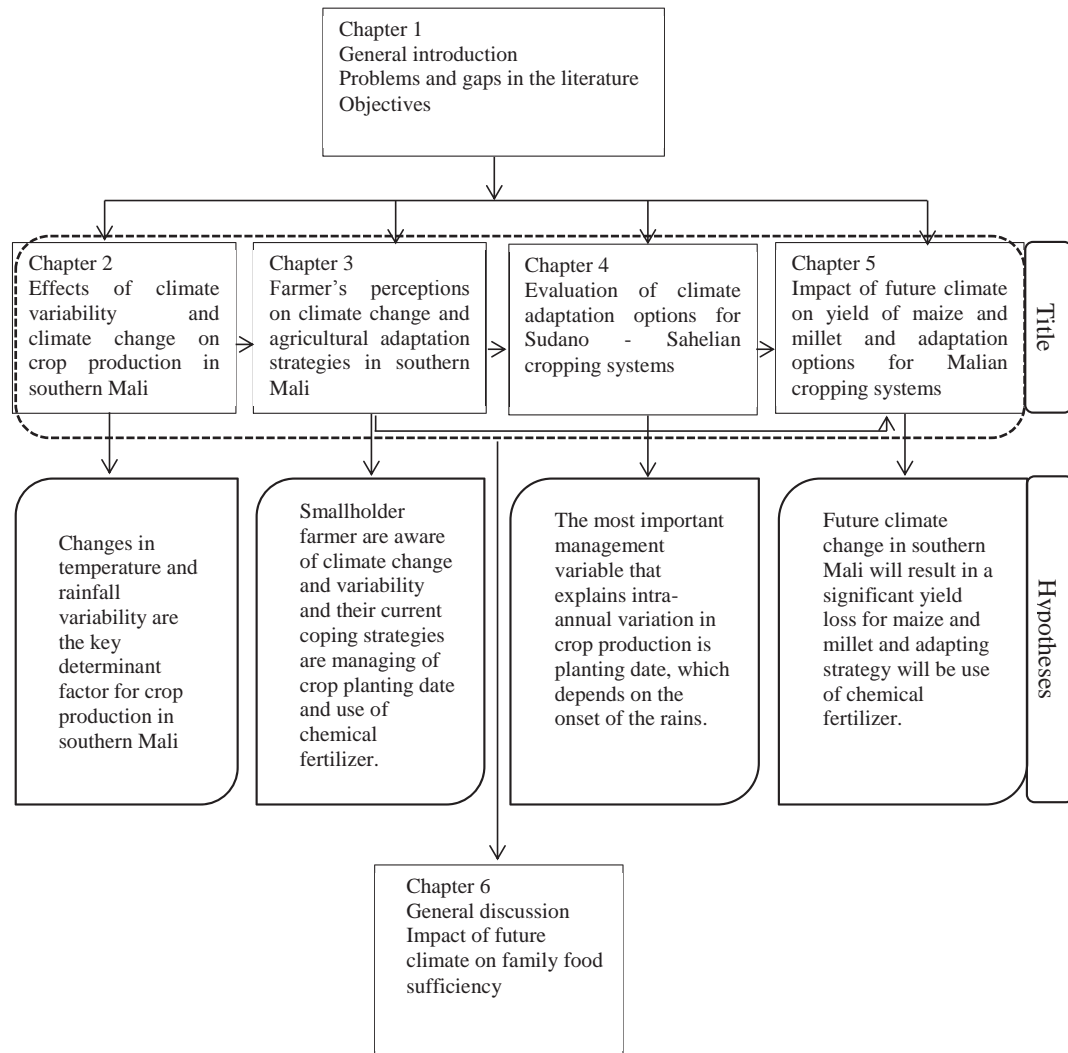


Fig 1.1: Thesis structure indicating connection between chapters and respective hypotheses

### **Outline of the thesis**

This thesis consists of six chapters (Fig 1.1), including this general introduction (Chapter 1). Chapter 2 to 5 contain the main findings of this study. All chapters have been written as independent research articles and published in /or to be submitted in peer reviewed journals. Chapter 2 evaluates the effects of climate change and climate variability on crop production in southern Mali. We used a long term climatic data to explore changes in climate trend in southern Mali together with long term experimental data from the N'Tarla research station and from on farm field trials to evaluate the effect of climate change and variability on yield of sorghum, groundnut and cotton.

In Chapter 3, we evaluate farmer's perceptions of climate change and climate variability by conducting individual farm surveys and group discussions. Diversifying crop cultivars, staggering planting date and application of fertilizer were identified as the major adaptation options to stabilize crop yields under uncertain rainfall conditions. We then set up participatory on-farm experiments on maize and millet to evaluate the above mentioned adaptations options as a means to cope and to adapt to climate change and variability.

In Chapter 4, we explore different cropping adaption options by using short, medium and long duration varieties and different planting dates of maize, millet, sorghum and cotton in a large on-station experiment for three years. This work was motivated by the erratic start of rainy season that can delay the planting date and result in yield penalties, and evaluates several options that farmers have to compensate for a late start of the growing season.

In Chapter 5, we use the crop model Agricultural Production Systems sIMulator (APSIM) to evaluate the sensitivity of maize and millet to predicted future climate change and climate variability. We first calibrated and tested the crop model of maize and millet using data from the three years experiment (Chapter 4). For constructing the climate change scenarios we used the average of future climate data provided by five global circulation models used within the framework of Coupled Model Intercomparison Project (CMIP5). Estimates are the potential change in maximum and minimum temperature and rainfall by the mid-century according to two emission scenarios based on two different scenarios for greenhouse gas emissions. The objective was to quantify the effect of changing climate on grain yield of maize and millet, and evaluate the potential of different adaptation options to compensate for the yield loss due

to climate change. We discuss the implication of the negative effect of climate change on crop production and farmer's livelihood in southern Mali

In Chapter 6, I place the impact of climate into the broader context of smallholder farming systems in the Sudano - Sahel region in West Africa, focusing on crop production. Impacts of climate on the food self-sufficiency of different farm types are quantified and discussed. Finally, the major conclusions drawn from the study are presented.

## Chapter 1- General introduction

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**Effects of climate variability and climate change on crop production in southern Mali**

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This chapter has been published as:

Traore, B., Corbeels, M., vanWijk, M. T., Rufino M. C., Giller, K. E. 2013 Effects of climate variability and climate change on crop production in southern Mali. *European Journal of Agronomy* 49: 115 – 125

### **Abstract**

In West Africa predictions of future changes in climate and especially rainfall are highly uncertain, and up to now no long-term analyses are available of the effects of climate on crop production. This study analyses long-term trends in climate variability at N'Tarla and Sikasso in southern Mali using a weather dataset from 1965 to 2005. Climatic variables and crop productivity were analysed using data from an experiment conducted from 1965 to 1993 at N'Tarla and from a crop yield database from ten cotton growing districts of southern Mali. Minimum daily air temperature increased on average by 0.05°C per year during the period from 1965 to 2005 while maximum daily air temperature remained constant. Seasonal rainfall showed large inter-annual variability with no significant change over the 1965-2005 period. However, the total number of dry days within the growing season increased significantly at N'Tarla, indicating a change in rainfall distribution. Yields of cotton, sorghum and groundnut at the N'Tarla experiment varied (30%) without any clear trend over the years. There was a negative effect of maximum temperature, number of dry days and total seasonal rainfall on cotton yield. The variation in cotton yields was related to the rainfall distribution within the rainfall season, with dry spells and seasonal dry days being key determinants of crop yield. In the driest districts, maize yields were positively correlated with rainfall. Our study shows that cotton production in southern Mali is affected by climate change, in particular through changes in the rainfall distribution.

**Key Words:** Climate change; Temperature increase; Rainfall variability; Cotton ; West Africa

## 2.1. Introduction

Since the early 1990s the Intergovernmental Panel for Climate Change (IPCC) has provided evidence of accelerated global warming and climate change. The last IPCC report concludes that the global average temperature in the last 100 to 150 years has increased by 0.76 °C (0.57°C to 0.95°C) (IPCC, 2007b). Finding evidence of global trends in rainfall is complex because of large regional differences, gaps in spatial coverage and temporal shortfalls in the data. Rainfall generally increased over the 20th century in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean region, southern Africa and parts of southern Asia (IPCC, 2007b). Furthermore, there is evidence for increases in the frequency of both severe droughts and heavy rains in many regions of the world. Climate change due to greenhouse gas emissions is expected to further increase temperature and alter precipitation patterns. All 21 General Circulation Models (GCMs) used by IPCC predict a temperature increase in sub-Saharan Africa in the order of 3.3°C by the end of the 21st century. With regard to predicted changes in rainfall amounts in sub-Saharan Africa, the uncertainty is considerably greater and in many instances models do not agree on whether changes in rainfall will be positive or negative (Cooper et al., 2008).

Rainfed agriculture produces nearly 90% of sub-Saharan Africa's food and feed (Rosegrant et al., 2002), and is major livelihood activity for 70% of the population (FAO, 2003). This agricultural sector is negatively affected by climate variability, particularly through heat waves, droughts, floods, and other extreme weather events. Overall, the success or failure of crop production under rainfed conditions in Sudano-Sahelian West Africa is strongly linked to rainfall patterns (Graef and Haigis, 2001b).

In West Africa, a combination of external and internal forces makes the climate of the region one of the most erratic in the world (Zeng, 2003). Annual cycles of rainfall are strongly determined by the position of the inter-tropical convergence zone (WCRP, 1999). Many studies have characterized the rainy season in West Africa; most of them were based on decadal, monthly or total annual rainfall analysis (Ati et al., 2002; Nicholson, 1980; Sivakumar et al., 1984) while others studies described the start and end of rainy season (Diop, 1996; Dodd and Jolliffe, 2001; Omotosho et al., 2000; Stern and Coe, 1982). A good understanding of seasonal variability patterns is of critical importance because of the highly unstable onset of the rainy season and the high frequency of dry spells. The last century's climate in Sudano-Sahelian West Africa was marked by high spatial and temporal variability

and by alternations between dry and wet seasons (Servat et al., 1998). A review by Traoré et al. (2007) of current knowledge on the regional climate in Sudano-Sahelian West Africa revealed that rainfall remains unpredictable. This rainfall unpredictability is a major constraint for farmers who have to plan the start of the cropping season (Piéri, 1989). The first rains are not always followed by the full start of the monsoon (Sultan and Janicot, 2003), dry spells can occur afterwards, i.e. during the early stages of the crop growth so that seeds may not germinate properly or germinated plants may die off. However, if sowing is delayed, the land may be too wet to till.

Southern Mali occupies 13.5% (approximately 160.825 km<sup>2</sup>) of the Malian territory. It represents 50% of the cultivable lands of the country and holds 40% of the Malian population. In southern Mali agricultural activities play an essential role in supplying food to the country; they represent 45% of the country's income (Deveze, 2006). Most people in the region are likely to be vulnerable to climate variability (Sivakumar et al., 2005). Hence, it is imperative to better quantify climate variability and change and their effects on crop production. Several studies analysing long-term relationships between climate and crop yields have been published recently (Kucharik and Serbin, 2008; Lobell and Burke, 2008; Lobell et al., 2008; Lobell and Field, 2007), but none of these focused on West Africa.

We analysed long-time series of weather data recorded in southern Mali, and crop yield data from an experiment at the Research Station of the Institut de l'Economie Rurale at N'Tarla and from farmers' fields in ten districts in southern Mali. The objectives of this study are therefore: (i) to quantify possible changes in climate and crop production over 30 years in southern Mali and (ii) to quantify the effect of annual climate variability and change on crop production.

## **2.2. Methods**

### **2.2.1. Study area and source of data**

The climate in southern Mali is typical of the Sudano-Sahelian zone. Average long-term annual rainfall is 846±163 mm at N'Tarla (12°35'N, 5°42'W 302 m. a. s. l.) and 1073 mm ± 187 at Sikasso ( 11°35'N, 5°68 W 374 m. a. s. l.). The rainy season extends from May to October and the seasonal average temperature is 29°C. During the dry season (November to April) the temperature and saturation vapour deficit increase and crop production is impossible without irrigation (Sivakumar, 1988).



The most common farming systems in the region are extensive mixed agrosylvo-pastoral systems, focused around cotton (*Gossypium hirsutum* L.) - the main cash crop- in rotation with cereals – sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R.Br.), maize (*Zea mays* L.) – and legumes – groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* (L.) Walp.). Cotton and to a lesser extent maize, receive nutrient inputs in the form of organic manure and/or chemical fertilizer, as well as pesticides. Other cereal crops seldom receive any fertilizer. As a result, soils are often mined and soil organic matter contents are declining (Piéri, 1989). Cattle, goats and sheep are the main livestock species. Agro-pastoralists generally practice sedentary farming, although due to large herd sizes and the lack of feed resources, transhumance is practiced in the dry season.

### **2.2.2. Climate data**

The meteorological data used for the climate analysis in this study were recorded at the meteorological stations of N'Tarla (12°35'N, 5°42'W 302 m. a. s. l.) and Sikasso (11°35'N, 5°68'W 374 m.a.s.l). The database contained long-term (from 1965 to 2005) records of daily rainfall and minimum and maximum temperatures. Daily minimum and maximum temperature were averaged over the rainy season to represent the seasonal temperatures. For the districts, we used the annual rainfall data as they were recorded at the different districts with rain gauges.

### **2.2.3. Long-term crop experiment**

An experiment was conducted from 1965 to 1993 at the N'Tarla agricultural research station (12°35'N, 5°42'W 302 m. a. s. l.) to determine the long-term impact of cotton-based cropping systems on soil fertility (IRCT, 1969). The trial was set up according to a Fisher block design with three crops (cotton, sorghum, groundnut) as part of a rotation, four fertilization treatments and four replications. Initially, a 3-year crop rotation cotton-sorghum-groundnut was used, from 1968 the crop rotation was cotton-sorghum-groundnut-sorghum and in 1976 returned to the 3-year rotation cotton-sorghum-groundnut. At the start of the experiment, the four fertilization treatments were: an unfertilized control, application of manure, application of mineral fertilizer and the combined application of manure and mineral fertilizer. The fertilizer treatments were modified over time, with the aim to limit soil fertility decline. In the first phase (1965-1979) of the experiment, mineral fertilizer and manure (9 t DM ha<sup>-1</sup>) were

applied only to cotton. From 1980 onwards, mineral fertilizer was allocated to the three crops and manure to cotton ( $6 \text{ t DM ha}^{-1}$ ) and sorghum ( $3 \text{ t DM ha}^{-1}$ ). Mineral fertiliser was then also applied in the control treatment. Weed and pest control were carried out on all treatments according to the standards recommended by the local agricultural research institute (IER/CMDT/OHVN, 1998).

The soils of the experimental site are highly weathered and classified as Lixisols (FAO, 2006). They have a sandy-loam texture ( $< 10\%$  clay) at the surface, but are richer in clay with depth ( $30\%$  at  $60 \text{ cm}$  depth). Soil organic carbon content is low ( $0.3\%$ ), pH is around 6 and CEC is less than  $3 \text{ cmol } (+) \text{ kg}^{-1}$ . They are typical soils for the region.

For the analysis of impacts of climate variability and change on crop production, we used only the crop yields of the treatment with the combined application of manure and mineral fertilizer. Since in this treatment there was no significant trend in soil carbon over time, we did not expect soil carbon or soil fertility in general, to have a strong influence on trends in crop yields. We, therefore, assumed that water was the main limiting factor. On the other hand, to evaluate the long-term effects of soil fertility on crop production, the crop yields in the control treatment were used.

#### **2.2.4. Crop yields from farmers' fields**

Crop yield data from ten cotton growing districts of southern Mali (Fig 2.1.) were obtained from the Malian cotton company (Compagnie Malienne pour le Développement des Textiles). From the available data, a database was developed with average yields at district level for cotton (1974-2005) and maize (1994-2005) together with the corresponding annual rainfall in the districts to evaluate yield-rainfall relationships. Yields from the database represent actual farmers' crop yields that were recorded by the cotton company in the villages of the respective districts.

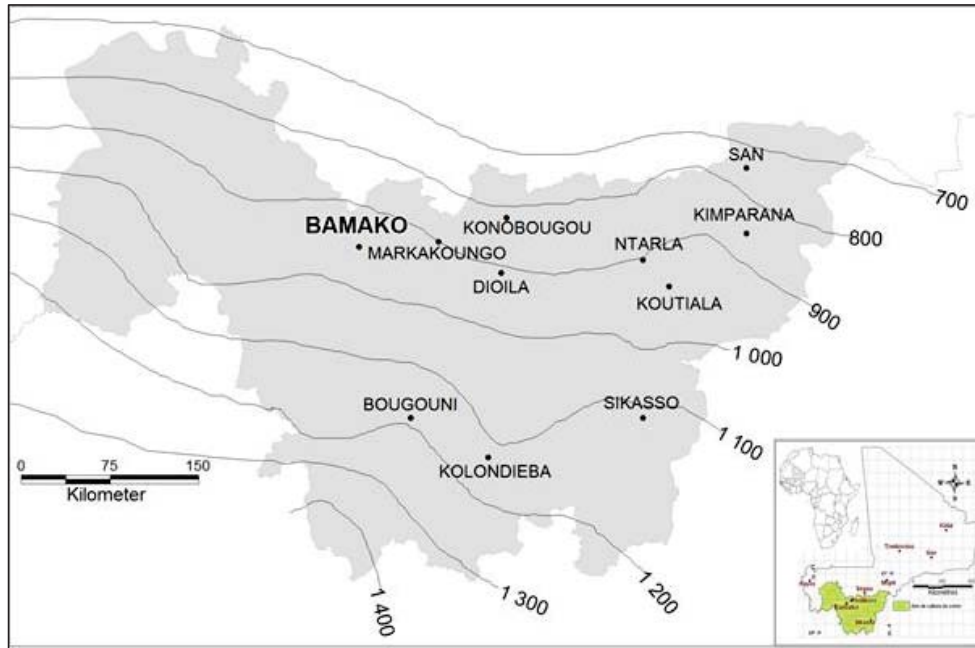


Fig 2.1.: Map of cotton districts in southern Mali with rainfall isotherms.

### 2.2.5. Climate analysis

The 41 years of daily weather data were analysed for changes in pattern and variability. Trends were examined using linear regression models with the rainfall and temperature as the dependant variables and year as the independent variable. Correlations coefficients ( $r$ ) were used to describe the relationships between the different variables. The variables included in the rainfall analysis were annual rainfall, number of rainy and dry days, date of start and end of the rains, the length of the rainy season and the distribution of dry spell periods of different lengths.

The start of the rainy season was defined as the moment when, counting from 1<sup>st</sup> May, cumulative rainfall for two consecutive days was larger than 20 mm and there was no dry period longer than 10 days with no rainfall within the following first 30 days after onset (Raman, 1974; Stern and Cooper, 2011; Stern et al., 1981). This period corresponds to land preparation and first sowing of crops. The end of the rainy season was defined as the moment when, starting from 15 September, there is a 10-day period without rain. In this period soil water is gradually depleted and the crops mature. Based on the annual values of the start and end date of the rainy season we calculated the length of the rainy season.

The occurrence of long dry spells during the growing season of a crop is a major agricultural hazard (Shaw, 1987; Stern and Coe, 1982); therefore we quantified the probabilities of the occurrence of dry spells of different lengths (Archer, 1981; Stern et al., 1981). A day was considered to be “dry” when daily rainfall was lower than 0.1 mm. The daily observations were represented as successive sequences of dry and wet periods and the total number of occurrences of 5, 7, 10, 15, 20 and 30 days dry spells across the years were calculated. The differences in probability of occurrence of certain dry spells between dry and wet years were analysed, and between years in which crop yield was high ( $>3 \text{ t ha}^{-1}$ ) and low ( $<1 \text{ t ha}^{-1}$ ) for cotton.

#### **2.2.6. Correlating crop yields and climate**

Crop yields from the N'Tarla long-term experiment were averaged per year across the different sequences in the rotation. The resulting yields of cotton, sorghum and groundnut were analysed for the 1965 to 1993 period by correlating them with meteorological variables using simple linear regression models. In addition, a statistical analysis was performed to determine relationships between differences (year-to-year changes) of crop yields and climatic variables such as temperature and annual rainfall (Lobell et al., 2005; Nicholls, 1997). Crop yield data from farmers' fields in ten cotton districts in southern Mali were correlated with annual rainfall over the period 1974-2005 for cotton and over the period 1994-2005 for maize using simple linear regression models.

### **2.3. Results**

#### **2.3.1. Observed climate trends**

Seasonal minimum daily air temperature increased significantly ( $P<0.01$ ) over time (Fig. 2.2.a) at N'Tarla and Sikasso with an average rise of  $0.06^{\circ}\text{C}$  per year for the period 1965-2005. The increase in seasonal maximum daily air temperature at N'Tarla was also significant during the period 1965-2005 ( $0.02^{\circ}\text{C}$  per year) (Fig. 2.2.b); the increase took place particularly between 1965 and 1993 ( $0.08^{\circ}\text{C}$  per year). In contrast, at Sikasso maximum air temperature decreased significantly by  $0.01^{\circ}\text{C}$  per year over the period 1965-2005. The average seasonal minimum and maximum temperatures over the period 1965-2005 were respectively  $23^{\circ}\text{C}$  and  $35^{\circ}\text{C}$  at N'Tarla and  $22^{\circ}\text{C}$  and  $33^{\circ}\text{C}$  at Sikasso. The number of dry days (Fig. 2.2.c) increased significantly between 1965 and 2005 at N'Tarla ( $P<0.05$ ) but not

( $P > 0.05$ ) at Sikasso. Over the period 1965–2005, no significant trend in annual rainfall was observed at either sites (Fig. 2.2.d), but rainfall decreased significantly between 1965 and 1993 at N'Tarla.

### 2.3.2. Rainfall variability

Both the number of dry days and seasonal rainfall showed interannual variability with a coefficient of variation of respectively 7% and 20% at N'Tarla and 12% and 17% at Sikasso. The start date of the rainy season was the most important factor determining the length of the season at both sites (Fig 2.3a); its relationship with the length of the season ( $r = -0.81$  at N'Tarla,  $r = -0.87$  at Sikasso,  $P < 0.01$ ) was much stronger than that of the end of the rainy season.

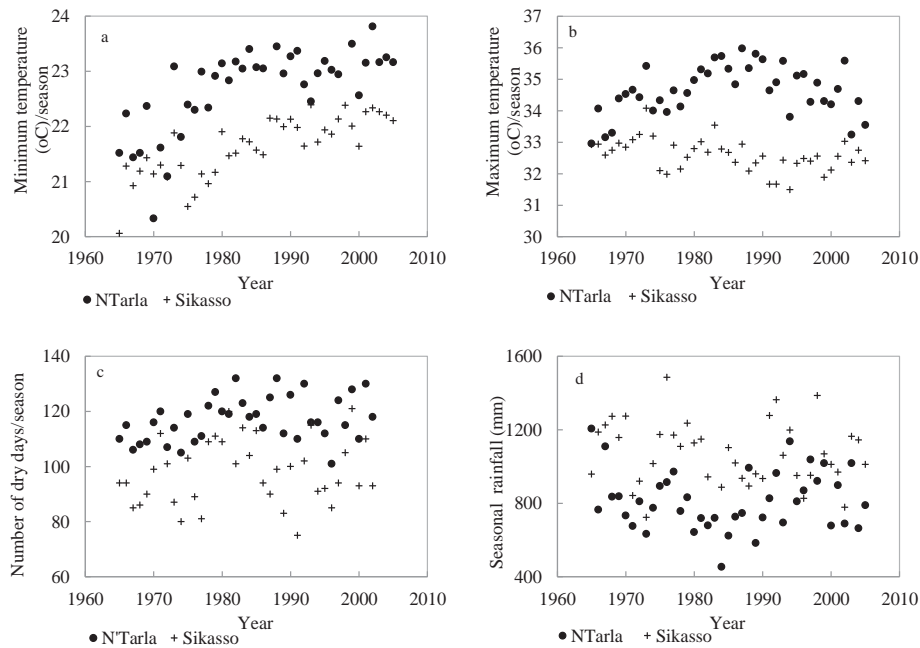


Fig 2.2.: Variation in climatic variables between 1965 and 2005 at N'Tarla, and Sikasso in southern Mali. (a) Regression of seasonal minimum temperature and year for N'Tarla:  $Y = 0.05x - 68.34$  ( $r = 0.70^{***}$ ,  $n = 41$ ) and Sikasso:  $Y = 0.04x - 50.12$  ( $r = 0.79^{***}$ ,  $n = 41$ ). (b) Regression of seasonal maximum temperature and year for N'Tarla:  $Y = 0.014x - 6.26$  ( $r = 0.20$ ,  $n = 41$ ) and at Sikasso:  $Y = -0.018x + 69.29$  ( $r = -0.44^{**}$ ,  $n = 41$ ). (c) Regression of seasonal dry days over the period 1965–2005 at N'Tarla:  $Y = 0.2x - 350$  ( $r = 0.33^*$ ,  $n = 41$ ) and at Sikasso:  $Y = 0.2x - 211$  ( $r = 0.15$ ,  $n = 41$ ). (d) Regression of seasonal rainfall and year for N'Tarla:  $Y = -0.12x + 1045.3$  ( $r = -0.13$ ,  $n = 41$ ) and at Sikasso:  $Y = -1.97x + 4967.8$  ( $r = -0.13$ ).

Start and end dates of the rainy season were not correlated and did not change over the period. The number of dry days and rainfall were significantly correlated ( $r = 0.66$  both at N'Tarla and Sikasso,  $P < 0.01$  Fig 2.3b). The length of the rainy season was significantly ( $r = 0.47$ ,  $P < 0.01$ ) correlated to the seasonal rainfall (Fig 2. 3c) at both sites.

### **2.3.3. Impact of climate on crop yields**

Before studying the relationship between crop yields and climate variables, we analysed the crop yield trends over the 30 years of experimentation at N'Tarla. Yields of cotton, sorghum and groundnut from the experimental treatment with combined application of mineral fertilizer and manure at the N'Tarla research station were highly variable from year to year with no clear trend over time (Fig 2.4). The coefficients of variation were respectively 27%, 45% and 40% for cotton, sorghum and groundnut. Correlating changes in sorghum and groundnut yields with changes in climate variables revealed no significant ( $P > 0.10$ ) relationship (Fig 2. 5. and Fig 2. 6.) while cotton yield was significantly ( $P < 0.05$ ) related to seasonal maximum temperature, rainfall and number of dry days (Fig 2.7).

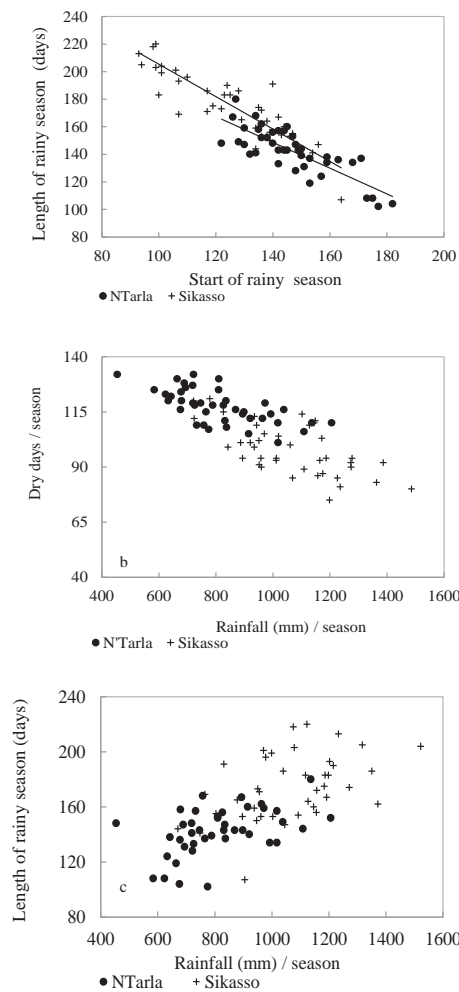


Fig 2.3.: Relationships between climatic variables from 1965 to 2005 at N'Tarla and Sikasso in southern Mali. (a) Regression of length of rainy season and onset date for N'Tarla:  $Y = -0.93x + 279$  ( $r = 0.65^{***}$ ,  $n = 41$ ) and Sikasso:  $Y = -1.176x + 323$  ( $r = 0.75^{***}$ ,  $n = 41$ ). (b) Regression of seasonal dry days and seasonal rainfall for N'Tarla:  $Y = -0.03x + 143.38$  ( $r = 0.66^{***}$ ,  $n = 41$ ) and Sikasso:  $y = -0.04x + 140.94$  ( $r = 0.64^{***}$ ,  $n = 41$ ). (c) Regression of length of rainy season and seasonal rainfall for N'Tarla:  $Y = 0.05x + 100.87$  ( $r = 0.47^{**}$ ,  $n = 41$ ) and Sikasso:  $Y = 0.07x + 100.79$  ( $r = 0.51^{**}$ ,  $n = 41$ ).

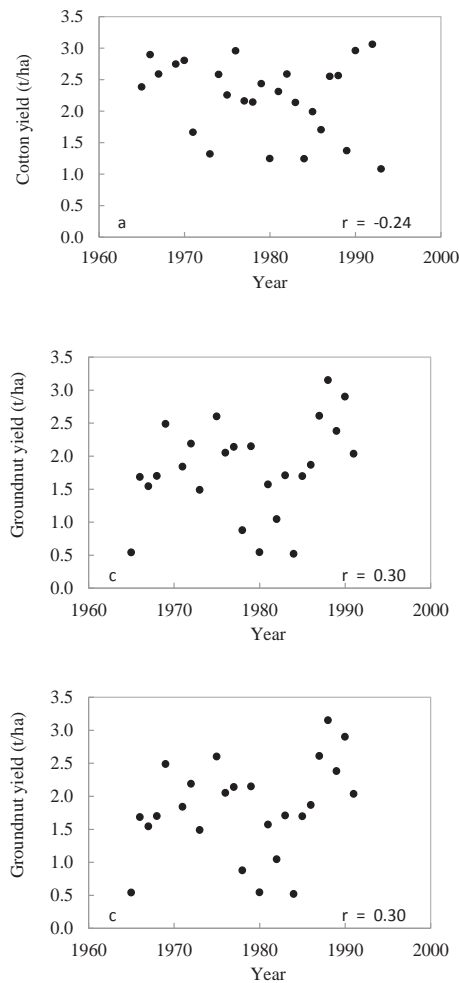


Fig 2.4.: Yields of cotton, sorghum and groundnut (t/ha) in the treatment with combined application of mineral fertilizer and manure in the long-term experiment conducted from 1965 to 1993 at N'Tarla agriculture

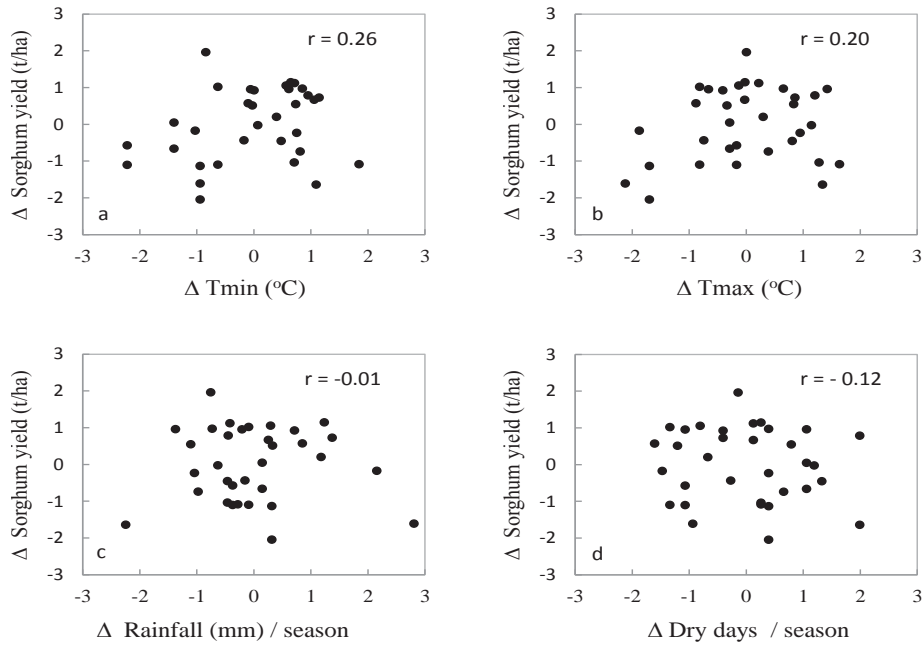


Fig 2.5.: Changes in mean yields of sorghum (t/ha) against change in seasonal minimum temperature, seasonal maximum temperature, seasonal rainfall and number of dry days in the long-term experiment conducted from 1965 to 1993 at N'Tarla agricultural research station in southern Mali. (Regressions are not significant for a, b, c and d.)



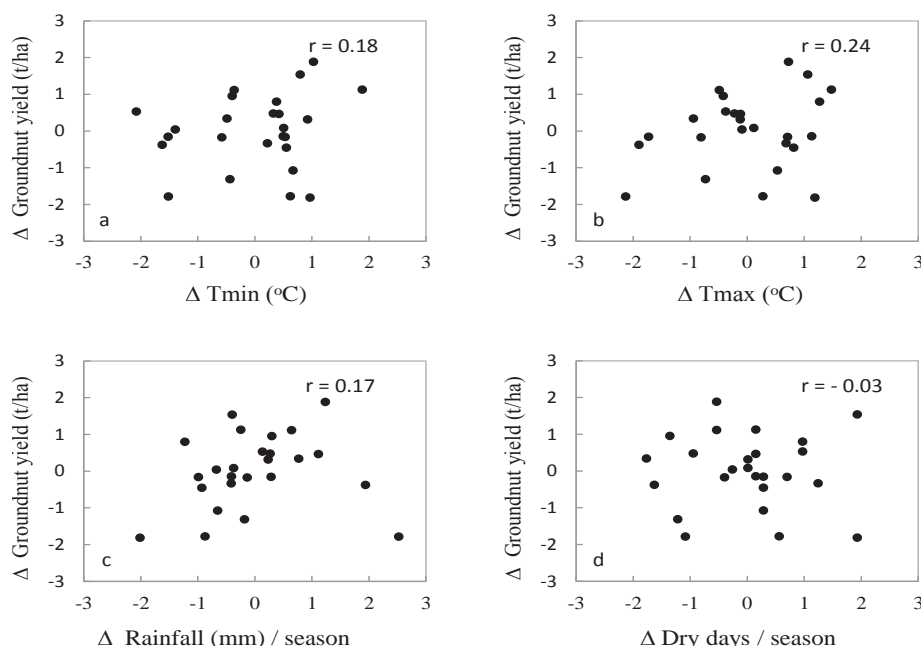


Fig 2.6.: Changes in mean yields of groundnut (t/ha) against change in minimum temperature, maximum temperature, annual rainfall and number of dry days in the long-term experiment conducted from 1965 to 1993 at N'Tarla agricultural research station in southern Mali. (Regressions are not significant for a, b, c and d.)

An increase of  $0.08^{\circ}\text{C}$  of maximum temperature during the rainy season corresponds to a yield loss of  $24 \text{ kg ha}^{-1}$  of cotton whereas the effect of the minimum temperature increase was insignificant. A wide range of cotton yields were observed for similar amounts of rainfall (Fig. 7c), and the relationship between rainfall and cotton yield resembles more a so-called step-function, represented by the dashed line in Fig. 7c. An important factor explaining this yield variation in the 'step' of the step-function is the rainfall distribution within a rainy season. Rainfall resulting in high yields (Fig. 7c, e.g. 1990) had a regular distribution during the early part of the growing season for cotton, whereas rainfall resulting in low yields (Fig. 7c, e.g. 1993) had an irregular distribution (Fig. 8). Within the period June - July there were 32 dry days in 1990 against 37 dry days in 1993. The effect of dry days during the rainy season on cotton yield was significant ( $P < 0.01$ ): an increase of one dry day during the rainy season lead to a yield loss of  $41 \text{ kg ha}^{-1}$ . Within the growing season, the increase of the number of dry days was significantly related to the number of 5-day and 7-day period dry spells (Fig. 9). It therefore seems that length of the dry spell is a good indicator for the quality

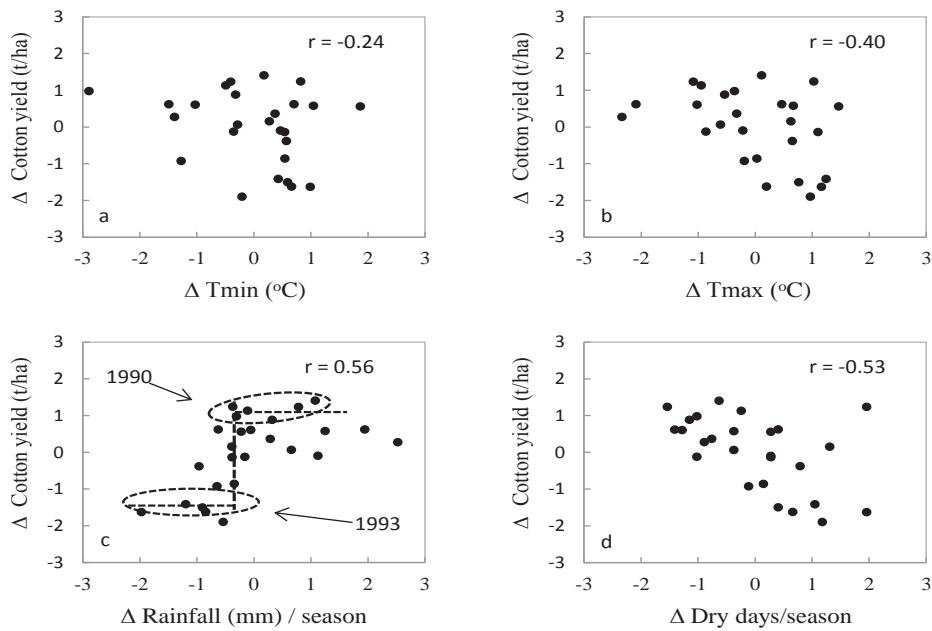


Fig 2.7.: Changes in mean yields of cotton (t/ha) against change in minimum temperature, maximum temperature, annual rainfall and number of dry days in the long-term experiment conducted from 1965 to 1993 at N'Tarla agricultural research station in southern Mali. Regressions are not significant for a but significant for b, c and d ( $P < 0.05$ ).

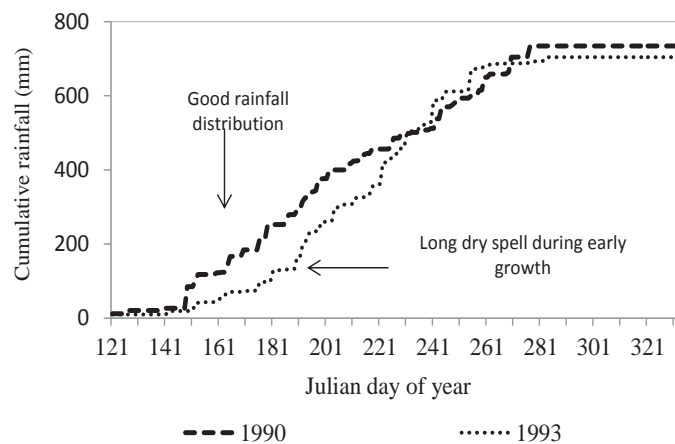


Fig 2.8.: An example of dry spell analysis for two contrasting years (1990 and 1993) that received similar cumulative rainfall at N'Tarla agricultural research station in southern Mali. The number of dry days was 132 in 1990 and 126 in 1993.

of the rainfall distribution within a growing season.

Multiple linear regressions indicated a significant effect of rainfall on cotton yield: on average 1 mm of rain is converted into 2 kg of cotton (Table 2.1). The estimated impact of the decline in seasonal rainfall between 1965 and 1993 on cotton was  $-17 \text{ kg ha}^{-1} \text{ year}^{-1}$ ,  $-4 \text{ kg ha}^{-1} \text{ year}^{-1}$  for minimum temperature, and  $4 \text{ kg ha}^{-1} \text{ year}^{-1}$  for maximum temperature (Table 2).

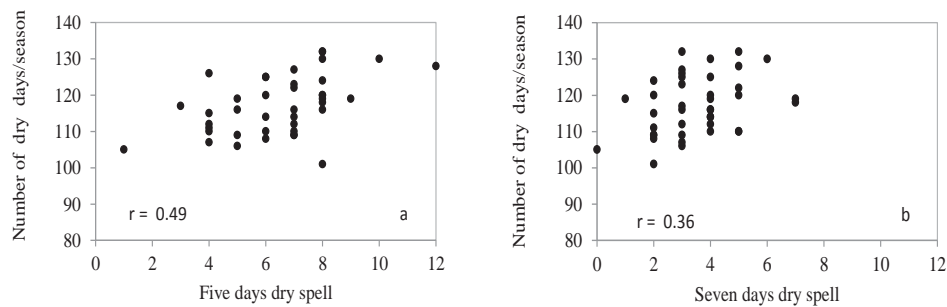


Fig 2. 9.: Regression between dry spells /season and number of five days dry spell (a) and seven days dry (b) periods in a year over the period 1965–2005 at N'Tarla agricultural research station in southern Mali. (a)  $Y = 1.9176x + 104.74^{***}$ , (b)  $Y = 1.9186x + 104.43^*$ .

Table 2.1: Multiple linear regression analysis of cotton yield and climatic variables in the long-term experiment conducted from 1965 to 1993 at N'Tarla agricultural research station, southern Mali.

| Variable                       | Estimate | SE   | t-value | P    |
|--------------------------------|----------|------|---------|------|
| Intercept (kg/ha)              | 256      | 7430 | 0.03    | 0.97 |
| <i>Yield effect of</i>         |          |      |         |      |
| Seasonal rain (kg/ha/mm)       | 2.1      | 0.95 | 2.18    | 0.04 |
| Seasonal $T_{\min}$ (kg/ha/°C) | -66      | 202  | -0.33   | 0.75 |
| Seasonal $T_{\max}$ (kg/ha/°C) | 53       | 267  | 0.2     | 0.84 |
| Multiple $R^2=0.31$ , $P=0.05$ |          |      |         |      |

Table 2.2: Trends of climatic variables and impact on cotton yields in the long-term experiment conducted from 1965 to 1993 at N'Tarla agricultural research station, southern Mali.

|                                 | Rainfall | $T_{\min}$ | $T_{\max}$ |
|---------------------------------|----------|------------|------------|
| Change/season                   | -7.5     | 0.07       | 0.08       |
| Estimated impact (kg/ha/season) | -15.47   | -4.29      | 4.24       |

The correlation of the average farmers' cotton yields in ten districts of southern Mali with annual rainfall indicated no significant ( $P>0.10$ ) relationship. There was a tendency towards a negative correlation in the wettest districts (Sikasso, Konlondieba and Bougouni) (Table 2.3).

On the contrary, average maize yields on farmers' fields showed a significant positive correlation with rainfall in the driest districts (San, Diola, Marakakoungo and Konobougou).

Table 2.3: Simple linear regression coefficients between cotton and maize yields against total annual rainfall in 10 cotton districts of southern Mali

| Cotton district | Cotton |        |          |       | Maize |       |          |       | Average rainfall (mm) |
|-----------------|--------|--------|----------|-------|-------|-------|----------|-------|-----------------------|
|                 | R2     | Slope  | estimate | Prob. | R2    | Slope | estimate | Prob. |                       |
| Koutiala        | 0.0    | 0.007  | 1128     | 0.965 | 0.09  | 0.481 | 1375     | 0.258 | 859                   |
| Mpessoba        | 0.07   | 0.132  | 1057     | 0.55  | 0.04  | 0.542 | 1169     | 0.49  | 887                   |
| Sikasso         | 0.03   | -0.176 | 1507     | 0.333 | 0.03  | 0.202 | 2100     | 0.467 | 1114                  |
| Bougouni        | 0.06   | -0.201 | 1322     | 0.169 | 0.04  | 0.326 | 1564     | 0.451 | 1126                  |
| Konlondieba     | 0.09   | -0.419 | 1580     | 0.123 | 0.14  | 0.787 | 880      | 0.313 | 1078                  |
| Kimparana       | 0.07   | -0.336 | 1157     | 0.212 | 0.00  | 0.12  | 1306     | 0.865 | 748                   |
| San             | 0.05   | 0.472  | 478      | 0.281 | 0.44  | 1.143 | 355      | 0.013 | 658                   |
| Diola           | 0.03   | -0.233 | 1362     | 0.353 | 0.2   | 0.783 | 1218     | 0.091 | 798                   |
| Marakakoungo    | 0.0    | 0.017  | 1113     | 0.941 | 0.24  | 0.922 | 930      | 0.059 | 787                   |
| Konobougou      | 0.0    | 0.038  | 956      | 0.909 | 0.23  | 0.865 | 1015     | 0.086 | 719                   |
| All districts   | 0.06   | 0.2724 | 855      | 0.001 | 0.32  | 0.988 | 871      | 0.001 | 862                   |

## 2.4. Discussion

### 2.4.1. Climate trends

Observed climate trends at two meteorological stations in southern Mali, N'Tarla and Sikasso, were similar. The increase in the annual minimum temperature of 0.5°C per decade observed at both stations is higher than the forecast rise of 0.3°C per decade on a global scale in the next century (Abrol and Ingram, 1997). In the Sahara region and West Africa warming is projected to occur more rapidly than the global average (GIEC, 2007).

There was a significant decrease in rainfall between 1965 and 1993 at N'Tarla, and a significant increase in the number of dry days. From the previous analysis at the scale of West Africa, Nicholson et al. (2000) concluded that a decrease in rainfall occurred during 1968–1997 with annual rainfall on average some 15 – 40% less in 1968-1997 than during the period 1931-1960. The period between 1965 and 2005 was especially marked by droughts during 1972-1973 and 1983-1984 with respectively 640 mm and 482 mm of rainfall at N'Tarla while at Sikasso it was 765mm and 671 mm. Our analysis showed that in terms of rainfall amount

and distribution, there is a clear indication that the Sikasso area is currently like what N'Tarla was 40 years ago, and that climate bands are shifting in the region.

There is considerable uncertainty about future rainfall patterns in West Africa (IPCC, 2007b). The clearest signal is the large proportional increase in rainfall from June to August in the Sahara where absolute amounts of rainfall are extremely small (Washington and Harrison, 2004). Overall, it is expected that more year to year variation in rainfall will occur in the majority of the zones where an increase in rainfall is projected (FAO, 2008b).

#### **2.4.2. Rainfall variability and associated risk for crop production**

The rainfall analysis revealed sequences of dry spells which affect cotton yields. The occurrence of dry spell of 5, 7, 10, 15 and 20 days was highest in May and October (results not shown). This point out the uncertainty of the regularity of rainfall in May which represents the land preparation period, which consequently may delay the planting date and reduce rainy season length. It also indicates the magnitude of the risk of planting in May. In the case of late planting, the grain filling period of varieties of maize such as Sotubaka with a growing cycle of 115 to 120 days extends until October which also corresponds to a period of high probability of dry spells. Frequent dry spell with high evapotranspiration demand may lead to a decrease in yield of up to 40% because of insufficient water supply during grain filling stage (Barron et al., 2003). Consequently, the significant increase of the number of dry days during the rainy season and its impact on yield makes it one of the most important characteristic of climate change in southern of Mali.

The start date of the rainy season was demonstrated to be the key variable to which all other seasonal rainfall variables are related. Many farmers are aware that rainy seasons with early onset are generally better for crop production than those with late onset (Sivakumar and Hatfield, 1990; Stewart, 1991). The lack of a clear relationship between the start and the end of the rainy season refutes the popular belief that late beginnings of the rainy season are compensated by late ending of rainy season or that rainy seasons become shorter because of a late onset and early end. In the south of the West African Sahel the rainy season starts earlier and ends later than in the north (Traore et al., 2007; Traoré et al., 2000). These characteristics of the Sudano-Sahélien climate are due to the north-south movement of the intertropical front (Diarra et al., 1987; Diop, 1996; Oladipo and Kyari, 1993; Sivakumar, 1988). An early start of the rainy season presents some risks as a long dry spell after planting may result in crop

failure. Conversely, a late end of the rainy season will make short-cycle cultivars prone to insect attack and bird damage (Stewart, 1991).

#### **2.4.3. Increased temperature and associated risk for crop production**

We observed no clear effects of changes in seasonal temperature on production of sorghum and groundnut. A detailed examination of the temperature records of N'Tarla and Sikasso shows that maximum daily temperatures do not exceed 36 °C, while minimum temperatures are above below 20 °C, which seems not to be a limiting factor for sorghum and groundnut production in southern Mali. However, there was a negative effect of increase in seasonal maximum temperature on cotton yield even though reported values in the literature of critical maximum temperatures are around 40°C (Reddy et al., 1992). Similar effects of temperature increases on rice yields were reported (Peng et al., 2004). Overall, the sensitivity of crops to a temperature increase varies among cultivars because plants have adapted to a relative wide range of thermal environments (Hartwell et al., 1997). C4 cereals such as sorghum respond better to increased temperature than C3 plants such as cotton (Sombroek and Gommers, 1997). Moreover, most of the sorghum and maize varieties grown in southern Mali are local types which may provide more flexibility for adaptation (Clement and Leblanc, 1980; Kouressy, 2002).

High temperatures or heat waves usually occur in conjunction with other environmental stresses such as drought and high light intensity (Rahman, 2006) which might lead to increased crop water requirements and therefore cause scalding in cereals (Burke, 1990), disturb flowering and strongly reduce crop yield (Fisher et al., 1997; Mackill et al., 1982; Zheng and Mackill, 1982). A recent meta-analysis of fully fertilized maize experiments in southern and eastern Africa showed that an increase in the temperature during the growing season can lead to a significant decrease of 3% in maize grain production (Lobell et al., 2011). For cotton, it is observed that the phase of boll formation is most sensitive to high temperatures (Reddy et al., 1992).

#### **2.4.4. Climate change, rainfall and crop production**

Analysis of data from the long-term cropping experiment at N'Tarla revealed that cotton is more affected by increase in maximum temperature than sorghum or groundnut. Annual variability in rainfall amounts, rainfall onset, number of dry days during the rainy season and

rainfall distribution was large, and determined variations in yield of cotton. Our analysis showed that the number of dry days is a good indicator of the quality of the rainfall distribution for cotton production, and was strongly related to cotton yield. It is clear from this analysis that the number of dry days is as important as seasonal rainfall. Under farmers conditions no clear impact of rainfall on cotton yields was observed, probably because other factors such as low soil fertility and insect attacks which are limiting yields (Kanté, 2001; Lançon et al., 2007), as suggested by the fact that lower yields were observed on farmers' fields than at the experimental site at N'Tarla. It should also be noted that in the wettest districts such as Sikasso, Bougouni and Konlondieba relatively high rainfall amounts might reduce cotton yields as a result of increased air humidity that support development of harmful insects which can cause rot of fruit bolls (Rahman, 2006). Effects of declining soil fertility on the cotton yield of the control treatment of the N'Tarla experiment (Fig 2.10.) were more important than effects of climate change during the period 1965 to 1980.

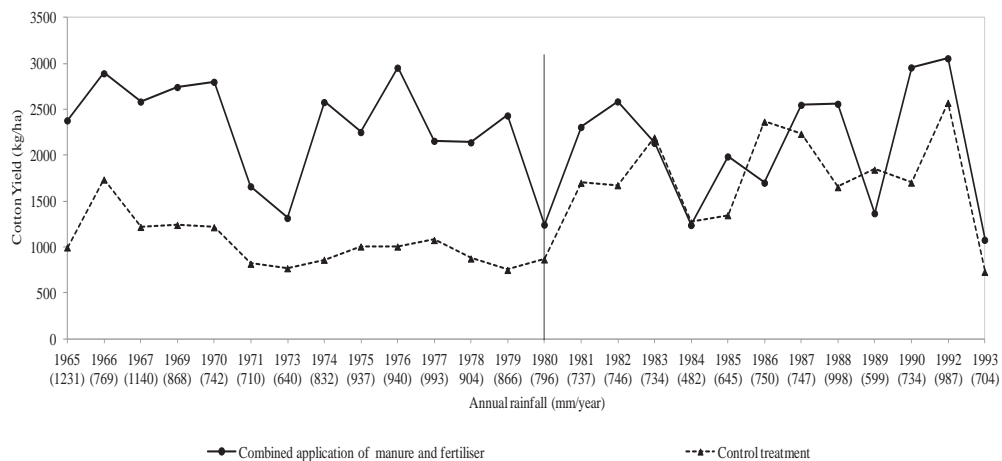


Fig 2.10.: Cotton yield trend per year under two rates of fertility management from 1965 to 1993 at N'Tarla agricultural research station, southern Mali. The vertical line indicates the start of using 163 kg ha<sup>-1</sup> of N in both treatments. Values in parentheses represent annual rainfall.

Interestingly, after full fertiliser application in 1980, average yields increased but also showed more year-to-year variability. This is possibly related to the fact that after fertilisation, nutrient limitation became less important than water availability for crop yields, thereby resulting in strong links between variations in growing season weather conditions and yield. In sub-Saharan Africa the issues of soil fertility management have dominated the debate on sustainability of farming for a long time (Breman, 2002; Piéri, 1989). Our findings stress that,

effects of declining soil fertility are certainly as important as those of climate effects (rainfall variability and number of dry days) at field level. However, disentangling effects of climate and soil fertility is not straightforward, and results depend on the spatial scale of analysis. Spatial variability of climate is an important factor affecting regional crop productivity in the arid and semi-arid regions (Sivakumar and Hatfield, 1990), a scale at which small-scale variations in soil fertility are averaged out and where long term trends in soil fertility decline are difficult to detect. Extrapolating our results to large scales is difficult because of a large spatial variability in soil fertility within distances as short as a few meters (Brouwer, 1993; Buerkert and Lamers, 1999; Manu et al., 1996) diversity in farm types and agricultural management practices (Soumaré et al., 2004; Traore et al., 2005). All of these factors affect the relative importance of changes in the driving variables of crop production, and it is therefore essential that studies make clear at which integration level their results hold: field, farm, landscape or regional level. A possible solution for this issue could be the use of dynamic crop growth simulation models directly linked to spatial databases containing detail information on soil properties, and management practices. Then the importance of the different factors could be unraveled at different integration levels. However, these databases do not exist at the moment.

The important characteristic determining the relationship between rainfall and crop production was the rainfall distribution which is related to the number of dry days during the rainy season. Better distribution of rainfall changes substantially the relationship between average seasonal rainfall and crop production (Lobell and Burke, 2008). This means that an average total amount of annual rainfall in Sahelian regions is not necessarily synonymous with good rainy season or with good crop production.

#### **2.4.5. Adaptive crop management strategies**

Traditionally, farmers cope with climate variability through risk-averse management practices such as the distribution of early and late crop maturity types throughout the landscape and spreading of sowing dates (Ouattara et al., 1998). This approach indicates that there is a great demand by farmers for climatic information at an intra-seasonal time scale. Accurate seasonal weather forecast information would help farmers to optimize their immediate decisions and tactical planning of crop management. Currently the predictability of seasonal rainfall is highly variable across Africa (Cooper et al., 2008).



An improvement in the seasonal weather forecasting skills and effective agrometeorology extension services are crucial for agricultural communities to adjust to future climate variability. Farmers could use this seasonal climate information to plan crop management tactically, such as adjusting planting and fertilization dates. Our finding shows that the late start of the season determined the length of the season provides an opportunity for farmers to adjust their management by planting shorter-duration varieties when the rains start late. Longer-term information on the nature of climate variability and change may help farmers to design new cropping systems and/or management that is more adapted to the climate. As an example to cope with increased dry spells, land management using contour ridging (Gigou et al., 2006) improves water use efficiency as rainwater on the field is channelled between the ridges, where it filters into the soil and reduces runoff. For cotton systems an alternative management practice based on a high plant density and the use of a crop growth regulators was tested as a way to cope with climate variability and change (Barrabe et al., 2007; Rapidel et al., 2006). With this new practice the crop covers the ground earlier, the cycle of production is reduced by 10 to 20 days which induces an adaptive behavior to climate variability and change, with yield increases of about 30 to 40% (Rapidel et al., 2009; Traore, 2011).

## **2.5. Conclusions**

Observed climate trends at two meteorological stations in southern Mali, N'Tarla and Sikasso, were similar. The main variable that characterised the rainfall season was the date of start of the rainy season which determines the length of the cropping period. Indeed, the delayed start of the rainy season also causes planting delays and therefore increases the risk of low plant production.

Overall, the impact of seasonal rainfall and maximum temperature variability on cotton yield is greater than that of the long-term changes in climatic variables. The important characteristic between rainfall and crop production is the rainfall distribution which is related to the number of dry days during the rainy season. The significant increase of the number of dry days during the rainy season over the period 1965-1993 and its impact on yield makes it one of the most important characteristic of climate change in southern of Mali. An average total rainfall in Sahelian regions is not necessarily synonymous with good rainy season or with good crop production. In our study which is based on an analysis at field level, it appears that the effects of declining soil fertility are as important as those of climate variability and change. However,

disentangling effects of climate and soil fertility is not straightforward, and results depend on the spatial scale of analysis.

**Farmer’s perceptions on climate change and agricultural adaptation strategies in southern Mali**

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2014 Farmer’s perceptions on climate change and agricultural adaptation strategies in southern Mali

### **Abstract**

Agricultural production in the Sudano-Sahelian zone of West Africa is highly vulnerable to the impacts of climate variability and climate change due to its dependence on rainfall. The present study aimed to understand farmers’ perceptions of climate variability and change and to evaluate adaptation options together with farmers, including tactical management of planting date and use of mineral fertiliser. Farmers perceived an increase in annual rainfall variability, an increase in the occurrence of dry spells during the rainy season, and an increase in temperature. Overall, this is in line with the observed meteorological data, except for the perceived decrease in rainfall during the growing season, which was not observed. Drought tolerant, short maturing crop varieties and appropriate planting dates were the commonly preferred adaptation strategies to deal with climate variability. Use of chemical fertilizer enhances the yield and profitability of maize while the cost of fertilizer prohibits making profit with fertilizer use on millet. Training of farmers on important aspects of weather and its variability, and especially on the onset of the rains, is critical to enhancing adaptive capacity to climate change.

**Key words:** rainfall, temperature, fertilizer, maize, millet, West Africa

### 3.1. Introduction

There is increasing evidence that climate change will strongly affect the African continent and will be one of the most challenging issues for future economic development, particularly in the dry regions of sub-Saharan Africa (Roudier et al., 2011). Smallholder agriculture will be strongly impacted (Sivakumar et al., 2005), given the limited adaptive capacity of regions dominated by poverty, subsistence farming, and a low agro-ecological potential (Galvin et al., 2001). Predictions indicate that due to climate change, national agricultural production earnings in Mali will decrease from 417 million US\$ in 1996 to 256 million US\$ in 2030 (Butt et al., 2005a). The extent to which the impacts will be felt depends largely on the adaptive capacity of the farmers. Rural communities in the Sahelian zone of West Africa have always managed their resources to face the challenge of variable environmental and socio-economic conditions (Mortimore and Adams, 2001), but the question is whether they will be able to continue to do this under a changing climate.

Adaptive capacity is widely recognized as a vital component of policy response to climate change. Without adaptation, climate change will hit the agriculture sector hard (Adger et al., 2003; Rosenzweig and Parry, 1994), but adaptation can soften the impacts (Waha et al., 2013a). The type of adaptation adopted is determined to a large extent by farmers' perceptions of climate change (Roncoli et al., 2001; Thomas et al., 2007).

Local knowledge and perceptions are not incompatible with more formal, scientific insights (Cleveland and Soleri, 2007). Rather, evidence suggests that farmers' perception based on their local knowledge must be integrated with research information and proposed technologies in order to successfully improve the adaptive capacity of rural smallholders (Mutiso, 1997.; Sillitoe, 1998). Little is known about farmers' perceptions of climate variability and change, and how these perceptions determine what farmers consider the best adaptation options (Vedwan, 2006) and how that affects the actual adoption of appropriate adaptation options. To guide future adaptation we need an understanding of past and current coping strategies, to better understand what is acceptable to farmers. This information in combination with farmers' perceptions of climate change and variability is key to prioritize measures to address and prepare for its consequences (Kitinya et al., 2012).

This study aims to capture the perceptions of a group of farmers in southern Mali on climate variability and change, and together with these farmers evaluates adaptation strategies including tactical management of planting dates and use of chemical fertiliser. Using open discussion and survey techniques, farmers' perceptions on climate change, impact of weather

aspects on crop production and potential adaptation options for dealing with climate anomalies were identified. This was combined with a 2-year field experiment in which effects of planting date and chemical fertilizer application on the grain yield of maize and millet were quantified and subsequently evaluated with farmers.

## **3.2. Materials and methods**

### **3.2.1. Study Area**

The study was conducted in the Try (12°35’N, 5°32’W, 335 m a.s.l.) and N’Goukan (12°27’N, 5°42’W, 409 m a.s.l.) villages in the Cercle de Koutiala, southern Mali. These villages were selected because of their representativeness of the region and their accessibility during all seasons. The climate of the study area is typical of the Sudano-Sahelian region. Average annual rainfall is around 850 mm, with a high inter-annual variability. The rainy season lasts from June to October with rainfall peaks in August. The dry season comprises a relatively cold period from November to February and a hot period lasting from March to May. The average maximum temperature is 34°C during the rainy season and 40°C during the hot dry period.

Cattle is a key component of the farming systems in the study region. Farmers commonly invest their earnings in cattle which also represent a social asset. Eighty per cent of farmers own at least one pair of oxen, a cultivator and a seeder, and use animal traction for soil preparation, weeding and sowing (Sanogo, 2010). Households who do not own oxen or equipment rent or borrow these from family or neighbours or cultivate their land manually. Until the 1960s, the cropping systems in the Cercle de Koutiala were characterized by long periods of fallow (with a duration of 15-20 years). However, with the introduction of animal traction and cotton cultivation, the practice of fallow has declined. Today, most land (especially, that close to the villages) suitable for agriculture has been put into production and fields are mostly permanently cropped. The largest share of the cultivated land in the Cercle de Koutiala is allocated to cereal production. Sorghum (*Sorghum bicolor*) and millet (*Pennisetum glaucum*) are the main crops representing, respectively, 38% and 32% of the cultivated area, but maize (*Zea mays*) is also important covering 12%. The cereals are grown in a two- or three-year rotation with cotton (*Gossypium hirsutum*) as follows: cotton-maize/millet/sorghum or cotton-maize-millet/sorghum. Fertilizer and pesticides are mainly applied to cotton and maize. Millet and sorghum usually do not receive fertilizer but benefit

from previous fertilizer applications to cotton or maize. Sorghum and millet are mainly used for home consumption. The proportion of maize that is sold is usually larger than that of sorghum and millet (Rietveld, 2009).

The landscape of the study area consists of a rocky plateau and valley bottoms with slightly sloping land in between. The soils are mainly Ferric Lixisols (FAO, 2006) with low clay content (<10%) in the top soil. Soils are in general moderately acid with a pH of around 6 (Hazelton and Murphy, 2007). Our own soil characterisations indicate that the organic C content ( $4 \text{ g kg}^{-1}$ ) is within the typical range (3 to  $5 \text{ g kg}^{-1}$ ) for the Sudano-Sahelian region (Veldkamp et al., 1991). Available P ( $17 \text{ mg kg}^{-1}$ ) is above the critical level of  $8 \text{ mg kg}^{-1}$  that was established for cereal crops in the region (Bationo et al., 1989).

In the cropped fields, the most common tree species – which are protected by local laws - are the shea-nut tree (*Vitellaria paradoxa*), neré (*Parkia biglobosa*) and baobab (*Adansonia digitata*). The fruits are used as a snack, especially during periods of food shortages, i.e. at the beginning of the rainy season. They are an important ingredient of local diets and serve as a vegetable fat, for example in combination with millet as a frying medium or added to porridge (Derks and Lusby, 2006). The collection, processing and commercialization of the fruits are almost exclusively under the control of women (Carney and Elias, 2006; Sidibé et al., 2012).

### **3.2.2. Perceptions of climate change, weather impacts on crop production and adaptation measures**

A workshop with farmers was organized to discuss climate (change), impact of weather events on crop production, and existing adaptation measures to climate variability. From each village 12 farmers were invited to join the workshop that was held in Koutiala situated at about 50 and 30 km respectively from N'Goukan and Try. Farmers were selected according to an existing farm typology that is based on land holdings, ownership of farming assets (plough, seeder, and cultivator) and number of cattle (ESPGRN, 1998). Farms of type A have a least 1 plough, 1 chart, 2 pairs of draught oxen and a least 10 heads of cattle and farms of type B have at least 1 plough, 1 chart, 1 pair of draught oxen and less than 10 heads of cattle. These farm types A and B are generally self-sufficient in staple food (cereal) and have more than 10 ha of land. They represent 80% of all farms in the region. Farms of type C have no complete set of plough with a pair of oxen and farms of type D perform manual cultivation. Farm of types C and D have less than 10 ha of land and are in general not self-sufficient in food. At

the workshop each farm type was represented by three farmers to cover the range of farm types in the study region.

Other invited partners to the workshop were the extension agents from the “Chambre d’agriculture”, and representatives of the cotton production company (Compagnie Malienne pour le Développement de Textile, CMDT). Researchers facilitated the debate and documented the discussions. The discussions aimed at identifying indicators of climate variability and change and impact of weather on crop production. Farmers were also asked about their strategies to cope with weather anomalies affecting crop production.

Based on the findings of the workshop discussions, a follow-up formal survey was carried out with the 12 farmers selected from each village to quantify the prevalence of farmers’ perceptions on climate change and on the appropriateness of various adaptation measures. Climate change indicators included changes in rainfall, length of the cropping period, length of the dry season, number of dry spells during the cropping period, rainfall during the dry season and start and end of the rainy season. Farmers were also asked about changes in maximum and minimum temperature and wind speed during the wet and dry season.

### **3.2.3. On-farm experiments**

A two-year (2010-2011) on-farm crop experiment was conducted to test some of the adaptation options to climate variability identified by the farmers. Diversifying crop species and cultivars, staggering planting dates and application of fertiliser were identified as the major adaptation options. Farmers decided to experiment with maize and millet, limiting a detailed study of crop diversification. Maize was chosen because it is less sensitive to drought than cotton, and is both a cash and food crop. Millet was chosen because it can be grown without the use of mineral fertiliser and because of cultural considerations related to taste and diet.

Farmers also decided which crop varieties to test. Maize variety Suwan 1 SR (CIMMYT/IITA), known as ‘Sotubaka’ in Mali, was chosen. It has a growth cycle of 110 to 120 days, and a height of 2.5-3 m. For millet, farmers preferred to experiment with their local variety ‘Kolonada’ with a growth cycle of 120 days and ear length of 60 cm.

Two fertilizer treatments were compared: the “Recommended Practice (RP)” i.e. the fertilizer rate according to the national research recommendations and the “Farmer’s Practice (FP)”. In the RP treatment each crop received the recommended rates (IER/CMDT/OHVN, 1998) of



compound NPK (16-16-16) fertilizer at planting and urea (46% N) at 40 days after planting. Maize received a total of 85 kg of N ha<sup>-1</sup>, 16 kg of P ha<sup>-1</sup> and 16 kg of K ha<sup>-1</sup>, and millet 39 kg of N ha<sup>-1</sup> 8 kg of P ha<sup>-1</sup> and 8 kg of K ha<sup>-1</sup>. For the FP treatment the rate of fertilizer varied from one farmer to another.

The experiments were conducted on small plots in farmers' fields. The size of each plot (for both treatments: RP and FP) was 56 m<sup>2</sup>, comprising seven rows of 10 m length. Farmers were asked not to change their current practice on the FP plots. Farming operations (e.g. weeding, hilling, ridging, harvesting) were carried out according to the current farmer practice both in RP and FP. Three planting dates were tested to cover the possible planting window for both crops in southern Mali: an early planting date in June (D1), a medium planting date in July (D2) and a late planting date in August (D3). Small variations in the different planting dates were allowed to accommodate farmers' labour availability. Farmers were split into three groups according to the three planting dates. However, in 2010, farmers in the D3 group did not want to delay planting until August, and planted in July. In 2011, the three planting dates were executed, but only in the RP treatments.

Crops were harvested after reaching physiological maturity. Yield was estimated from a net plot of 24 m<sup>2</sup> (3 rows of 10 m length) in the centre of the plot to avoid border effects. Cobs were separated from stover and transported to the research station at N'Tarla for further processing. Grains were separated from the cob, dried and weighed. Over the two years of the experiment, daily rainfall on each individual field was measured with a rain gauge by a trained family member. Soil samples were taken from a depth of 0 to 20 cm at each farmer's field before the start of the rainy season (April-May) in 2010 and analysed for pH, soil organic C and available P.

The economic performance of treatments was assessed on the basis of gross margin, calculated as the value of production minus the variable cost of production. The price of chemical fertiliser (compound and urea) was 250 CFA per kg, and the average selling prices of maize and millet were respectively 180 CFA and 125 CFA kg<sup>-1</sup> grain (OMA, 2012).

#### **3.2.4. Statistical analysis**

The effect of fertilizer treatment (RP and FP) and location (the village of Try and N'Goukan) on grain yields of maize and millet were analysed using ANOVA procedures for a split plot design (GenStat Edition 14<sup>th</sup> Library Release Pl 18.2, VSN International Ltd). Villages were

chosen as the main (fixed) factor and fertilizer treatment as the sub-plot (fixed) factor. Farm was considered as a random factor. The Restricted Maximum Likelihood (REML) procedure was used to test the individual effect of fertilizer treatment (RP and FP), chemical fertiliser (N), pH, soil organic C, C to N ratio, available P, planting date and rainfall on the grain yields of maize and millet. For each crop the analysis was performed for 2010 and 2011 separately.

### **3.2.5. Evaluation of the experiment by farmers**

At the end of the field experiment a group discussion was organised with all 24 farmers to evaluate the main results of the experiment. Opportunity was given to farmers to give their opinion on the difference between the yields obtained with the recommended practice and the farmer’s practice. The main lessons learned with respect to cropping under erratic rainfall conditions were also formulated.

## **3.3. Results**

### **3.3.1. Farmers’ perceptions**

#### Climate change

The majority (84%) of the farmers at the workshop claimed that total annual rainfall is decreasing in the region. Only 8 % of the farmers reported no change and attributed this view to the high year to year variability (Table 3.1). None of the respondents mentioned that annual rainfall may have increased. All farmers felt that the length of the cropping period had shortened, while 84% claimed that the dry season had been prolonged. The majority of the farmers mentioned that the change in the rainy season is characterised by a later onset (92% of the respondents), and an earlier end (79%), thus explaining the shortening of the rainy season (Table 3.1). Farmers also characterised the change in rainfall pattern by an increase in the frequency of dry spells during the rainy season. About half of the farmers found that there was an increase in temperature throughout the year, and a majority (71% of farmers) felt that the length of the cold period had not changed. Finally, wind intensity was pointed out by 83% of the farmers to have become stronger, especially during the dry season (Table 3.1).

#### Impacts of weather anomalies on crop production

The main weather anomalies mentioned by farmers that impact crop production were related to the seasonal rainfall pattern (Table 3.2.), i.e. a late start or an early end of the rainy season,

low seasonal rainfall, and the occurrence of dry spells at any stage of the crop growing season. Strong winds and high temperatures were also perceived as causing damage to crops (Table 3.2). In general, crop production was affected through poor seed germination, full crop failure as a result of drought or damaged crops due to strong winds.

Table 3.1: Perception of change in different climate indicators by farmers in N’Goukan and Try, Mali

| Climate indicator                            | Increase | No change | Decrease | No opinion |
|--|----------|-----------|----------|------------|
| Annual rainfall                              | 0        | 8         | 84       | 8          |
| Length of cropping period                    | 0        | 0         | 100      | 0          |
| Length of dry season                         | 84       | 8.0       | 0        | 8          |
| Dry spells during cropping period            | 96       | 4         | 0        | 0          |
| Rainfall during dry season                   | 4        | 8         | 79       | 8          |
| Temperature during dry season (March to May) | 63       | 17        | 16       | 4          |
| Temperature during cropping period           | 54       | 17        | 21       | 8          |
| Length of cold period (November to February) | 8        | 71        | 8        | 13         |
| Change in wind intensity                     | 83       | 0         | 0        | 17         |
|  | Later    | No change | Earlier  | No idea    |
| Start of rainy season                        | 92       | 8         | 0        | 0          |
| End of rain season                           | 0        | 21        | 79       | 0          |

Number of respondents = 24

Table 3.2: Farmers’ perceptions of impacts of weather anomalies in Try and N’Goukan, Mali

| Weather indicator  | Impact   |
|--|--|
| Deficit in seasonal rainfall amount                              | Crop water deficit resulting in yield loss   |
| Late start and early end of rainy season                         | Crop water deficit resulting in yield loss; long cycle varieties fail                        |
| Low rainfall in dry season                                       | Spreading manure less effective; manure decomposition slowed down and reduced manure quality |
| Dry spells at the end of season or early cessation of the season | Crop water deficit resulting in poor crop maturation   |
| Prolonged dry spells in the early stages of the rainy season     | Crop water deficit resulting in seedling death   |
| Strong wind  | Soil erosion resulting in low soil fertility   |
| High temperature   | Crop heat stress and resulting yield loss  |

#### Adaptation measures

The most common measures to cope with weather anomalies in cropping systems included adjusting planting time, use of short-duration varieties and crop diversification (Table 3.3). Although more than 50% of the farmers were satisfied with these strategies, around 25% of the farmers were not, mainly because of a reduction in grain yields with a delay in planting date. The dissatisfaction about the use of short-duration varieties compared with the local varieties is related to their susceptibility to fungal diseases during storage of the grains. Also the new sweet sorghum variety (‘Tiendougou’), which is being promoted by the national research institute and AGRA (Alliance for Green Revolution in Africa), is not very popular with farmers due to its susceptibility to diseases. Reseeding was mentioned as an adaptation measure to early-season dry spells, but more than 50% of farmers were not satisfied with this because it implies extra costs (seed) and labour, often at times of peak labour demands. Planting hedgerows was seen as a strategy to cope with wind erosion, although most farmers thought this takes many years to be effective and requires substantial investment that they often cannot afford. The common practices for soil fertility improvement such as applying manure and chemical fertilizer were mentioned as a means to rehabilitate degraded soils and prevent wind erosion. However, 93% of the farmers were only moderately or not satisfied with these practices, because of the lack of cattle or equipment (cart) for the production and transportation of the manure to the fields, which could be situated up to 5 km from their homes. Also the high cost of chemical fertilisers was mentioned as a drawback.

Table 3.3: Percentage of farmers highly (+), moderately (+/-) or not satisfied (-) with adaptation measures to deal with weather anomalies in Try and N’Goukan, Mali

| Weather indicator                           | Adaptation measure                                | Number of respondents | +  | +/- | -  |
|---|---|-----------------------|----|-----|----|
| Deficit rainfall resulting in yield loss    | Adjusting planting date                           | 11                    | 27 | 46  | 27 |
|   | Short duration variety                            | 18                    | 17 | 61  | 22 |
|   | Crop diversification                              | 22                    | 19 | 72  | 9  |
| Erratic rainfall at the start of the season | Reseeding   | 14                    | 7  | 36  | 57 |
| Wind erosion leading to soil degradation    | Produce more manure and supply mineral fertilizer | 15                    | 7  | 73  | 20 |
|   | Green fence                                       | 11                    | 18 | 27  | 55 |

### 3.3.2. On-farm experimentation

#### Rainfall

Seasonal rainfall was very similar at N'Goukan and Try and characterised by low spatial variation. In 2010, at N'Goukan, the average rainfall across farms was 1465 mm with a coefficient of variation (CV) of 3%, while at Try the average rainfall was 1358 mm with a CV of 4%. In 2011, at N'Goukan, the average rainfall was 806 mm with a CV of 6%, whereas at Try 829 mm was recorded with a CV of 8%. The difference between both years was high: rainfall recorded in 2010 was 45 and 39% higher than that recorded in 2011 at N'Goukan and Try respectively. In 2011, after the first rainfall there was a series of 13 and 16 continuous dry days at N'Goukan and Try respectively (Fig 3. 1).

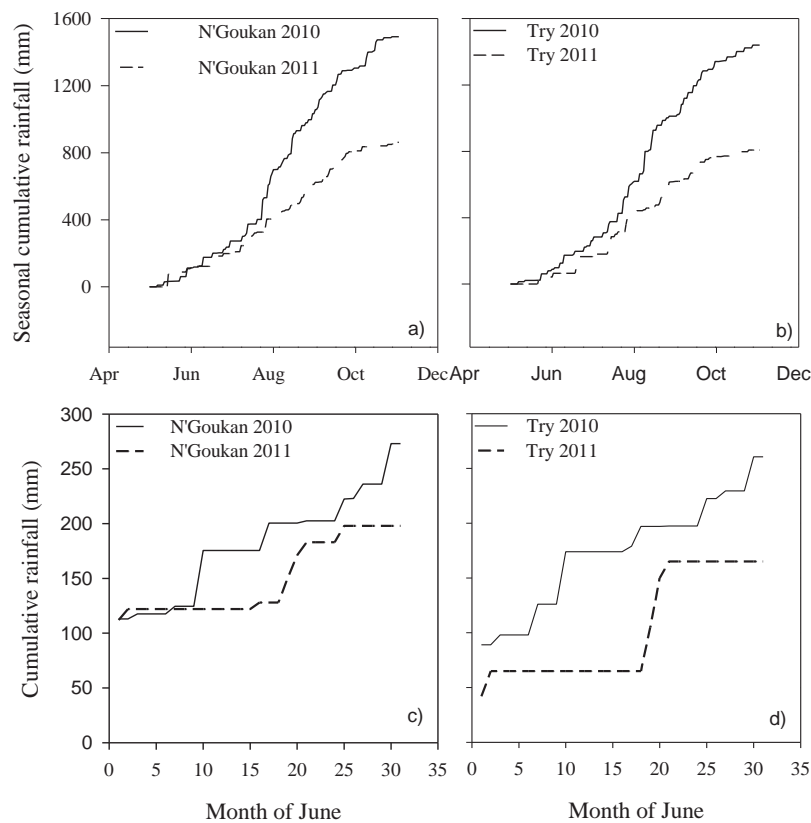


Fig 3.1: Seasonal cumulative rainfall (a and b) and the cumulative rainfall distribution during the month of June (c and d) representing the start of rainy season) in 2010 and 2011 at N'Goukan and Try

#### Crop yields under farmer's practices and recommended practice

Both in 2010 and 2011, maize and millet grain yields obtained with RP were significantly larger than those with FP ( $P < 0.05$ ), while the differences in yields between the villages were not significant (Fig 3.2).

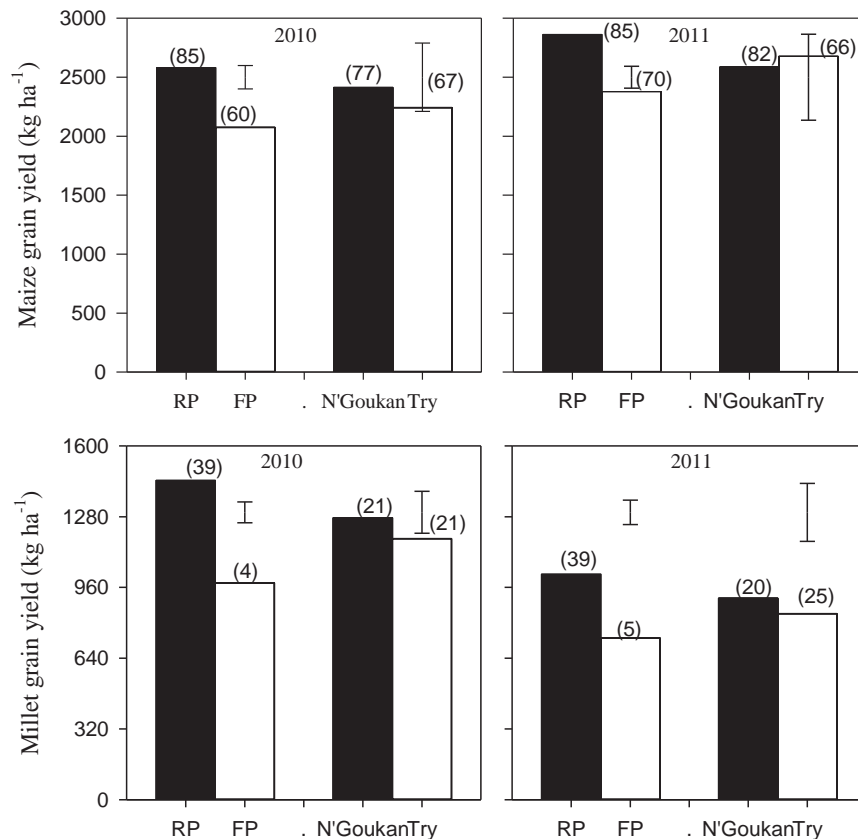


Fig 3.2: Yield of maize and millet with Recommended Practice (RP) and with Farmer Practice (FP). Value in between parentheses indicates the amount of chemical N applied (in kg ha<sup>-1</sup>). Error bars show the SED (Standard Error of the Difference).

The cumulative probability distribution of maize yields across farms in 2010 indicated that in both treatments more than 50% of the recorded yields was larger than 2000 kg ha<sup>-1</sup>, which is the upper boundary of the national average yield range (CPS 2010). 2011 was a slightly better year for maize as the 2000 kg ha<sup>-1</sup> threshold was obtained in at least 60% of the cases. In 70% of the cases for FP and only 30% for RP, the recorded millet grain yields were below the 1000 kg ha<sup>-1</sup> upper boundary of the national average yield range (Fig 3.3). In 2011, 90% and 40% of the records for FP and RP respectively were below the 1000 kg ha<sup>-1</sup> threshold.

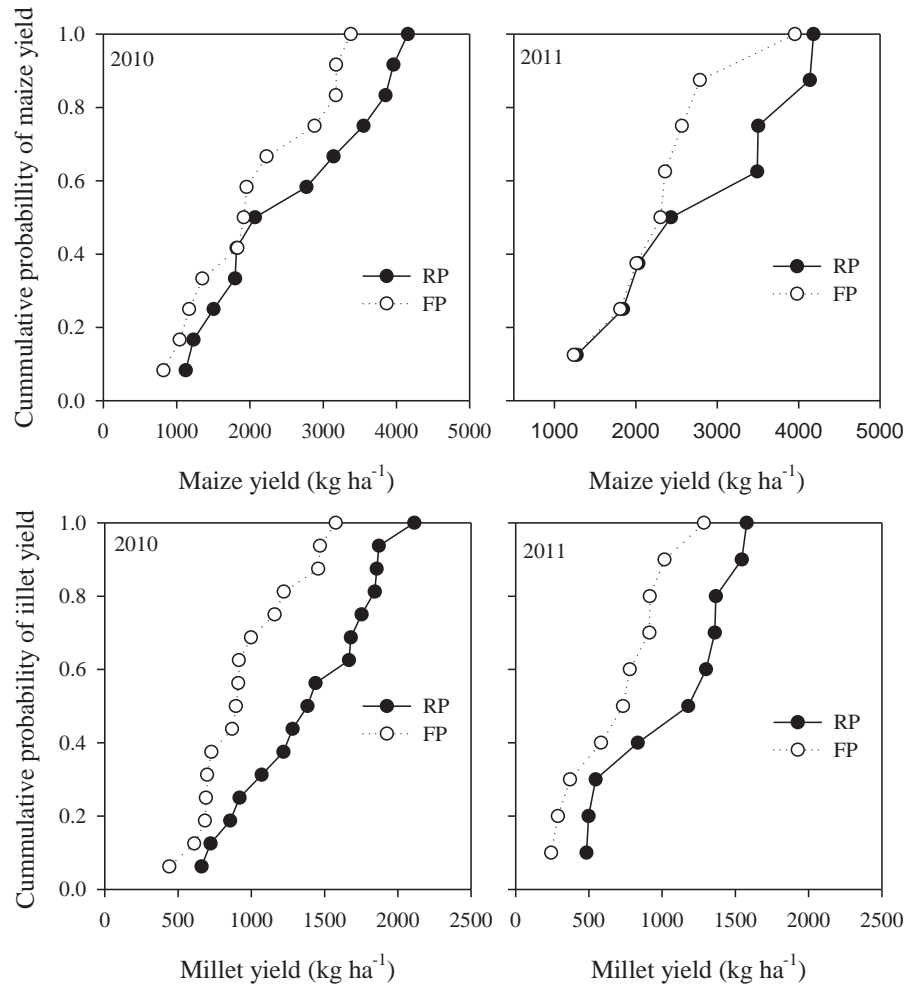


Fig 3.3: Empirical cumulative probability distributions of the maize and millet yield with Recommended Practice (RP) compared to Farmer Practice (FP) in 2010 and 2011 at N’Goukan and Try. Note the different scale of the x-axis for maize and millet.

#### Yield determinants

##### Seasonal rainfall

There was a positive relationship between the grain yield of maize and seasonal rainfall recorded from planting date till harvest (Fig 3.4). The correlation was significant in 2010 for maize with RP ( $P=0.04$ ), but not with FP ( $P=0.13$ ). In contrast, the relationship was significant in the drier year 2011 for both RP ( $P=0.07$ ) and FP ( $P=0.03$ ) indicating the sensitivity of maize yield to the seasonal rainfall amount. For millet no significant correlations were found between yield and seasonal rainfall, neither in 2010 nor in 2011 for RP and FP.

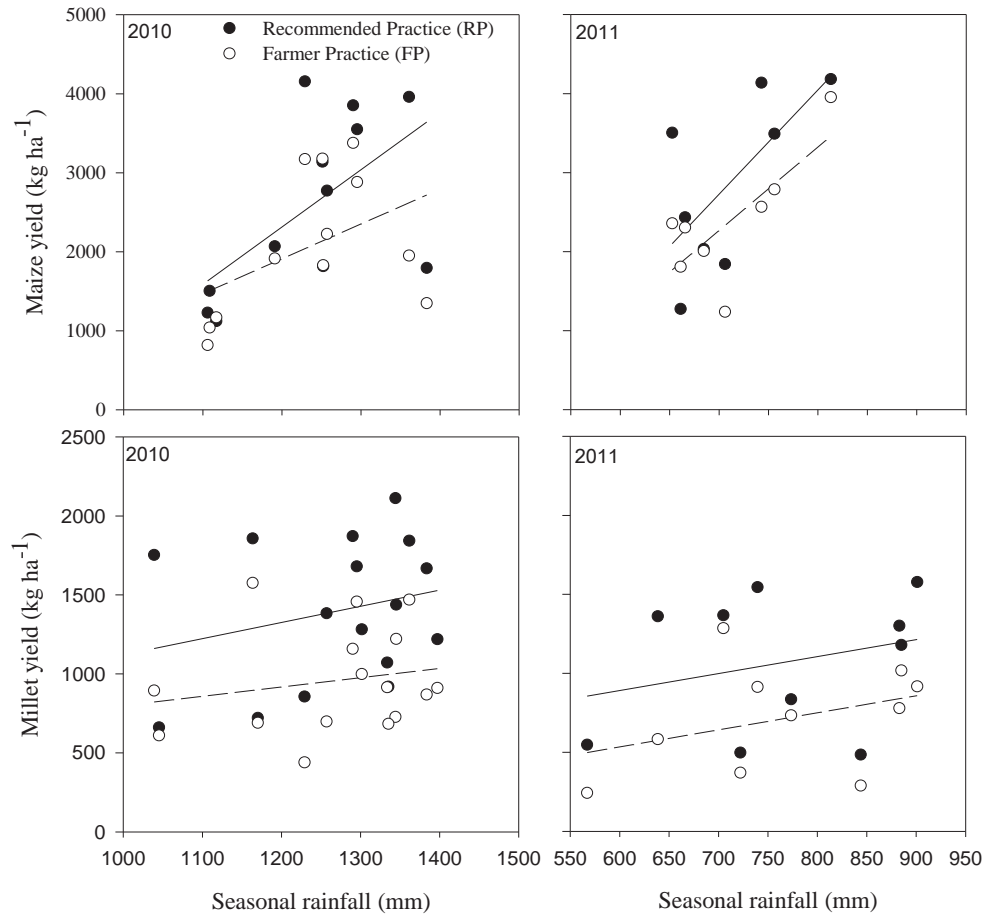


Fig 3.4: Scatterplots of maize and millet yield against seasonal rainfall recorded from planting until harvest with fitted regression lines for Recommended Practice (RP, full line) and Farmer Practice (FP dashed line). Note the different scales of the axes for the years and the crops. In 2010, data for the first (D1) and second (D2) planting date are shown, and for 2011, only D1 data are shown.

#### Planting date

In 2011, maize grain yield at early planting (D1) was significantly higher than that obtained at medium planting (D2), which was in its turn significantly higher than that at late planting (D3) ( $P < 0.01$ ) (all RP). However, even with the same planting date variability in maize grain yields across farm fields was high (Fig 3.5). Also in the case of millet, grain yields decreased significantly ( $P < 0.01$ ) with a delay of planting, and varied significantly from one field to another, even if planted at the same time (Fig 3.5). Under RP conditions, maize yielded significantly more grain than millet at all planting dates (Fig 3.6).



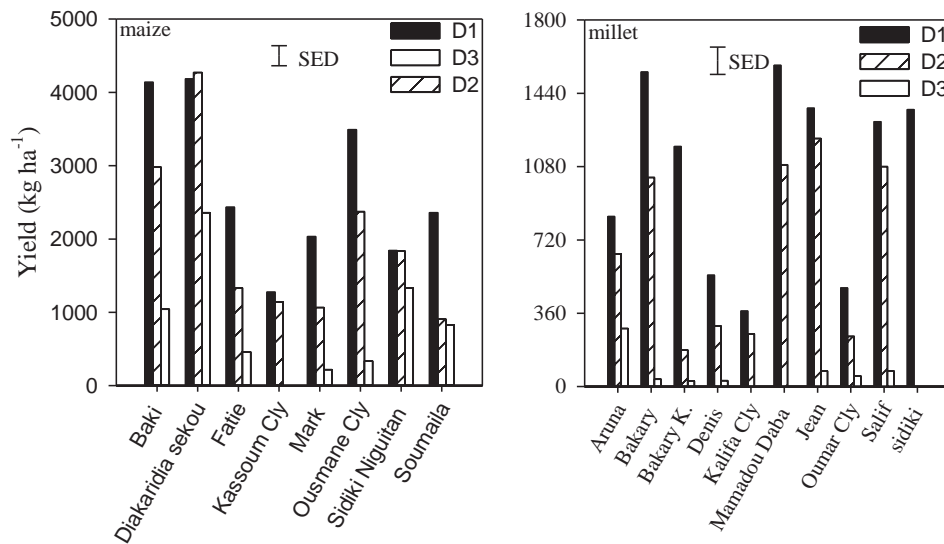


Fig 3.5: Yield of maize and millet in 2011 with the recommended practice at farmers' fields and three planting dates (D1 earlier planting, D2 medium planting and D3 late planting). Note the different scale of the y axis between the two graphs.

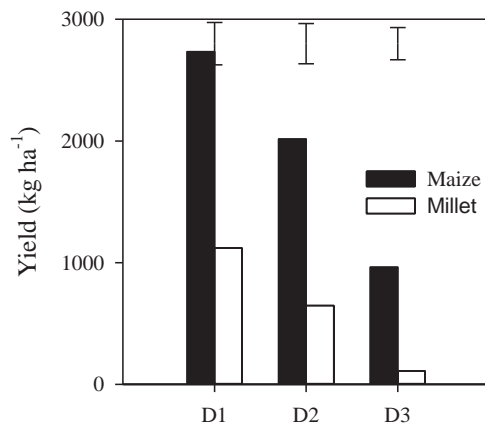


Fig 3.6: Average grain yield of maize and millet across farmers' fields in 2011 with recommended practice at early (D1), medium (D2) and late planting (D3). Error bars show the SED (standard error of the difference).

## Soil fertility and fertilization

The mixed linear model analysis indicated that in both years there was a significant effect of fertilizer treatment (FP or RP) and of soil organic C content on maize grain yield. In addition to these variables, there was a significant effect of pH on maize yield in 2011 (Table 3.4). Under farmer practices, there was a significant relationship between maize yield and chemical N fertilizer in 2011 ( $P < 0.10$ ). Nitrogen supplied as urea was more effective ( $P < 0.05$ ) than that of compound fertilizer ( $P > 0.10$  not shown). For millet, apart from the fertilizer treatment (FP or RP), there was no significant effect of the other soil fertility variables neither in 2010 nor 2011 (Table 3.4).

Table 3.4: P-values for the different variables explaining the variability in observed on farm experimental yields of maize and millet. Values were calculated using the Restricted Maximum Likelihood procedure

|                 | Maize |       | Millet |       |
|-----------------|-------|-------|--------|-------|
|                 | 2010  | 2011  | 2010   | 2011  |
| FP/RP Treatment | 0.019 | 0.005 | 0.001  | 0.027 |
| Fertilizer*     | 0.166 | 0.081 | 0.169  | 0.804 |
| pH              | 0.238 | 0.005 | 0.814  | 0.568 |
| C_N             | 0.342 | 0.178 | 0.638  | 0.698 |
| Organic_C       | 0.077 | 0.052 | 0.679  | 0.925 |
| P               | 0.296 | 0.564 | 0.711  | 0.46  |
| Village         | 0.437 | 0.050 | 0.551  | 0.681 |
| Annual rainfall | 0.849 | 0.010 | 0.735  | 0.151 |
| Date**          | 0.83  | 0.010 | 0.124  | 0.844 |

\* comparison restricted to FP. The number of observations is 10 and 7 for maize in 2010 and 2011 respectively. For millet it is 15 and 10 in 2010 and 2011 respectively.

\*\* comparison restricted to RP

## Gross margin

The gross margin for maize obtained with RP was significantly larger than that obtained with FP at N’Goukan in 2010 and 2011, while at Try the difference was not significant for any year ( $P > 0.10$ , Fig 7). Although not significant, the millet gross margin was less for FP than for RP in both villages (Fig 7).

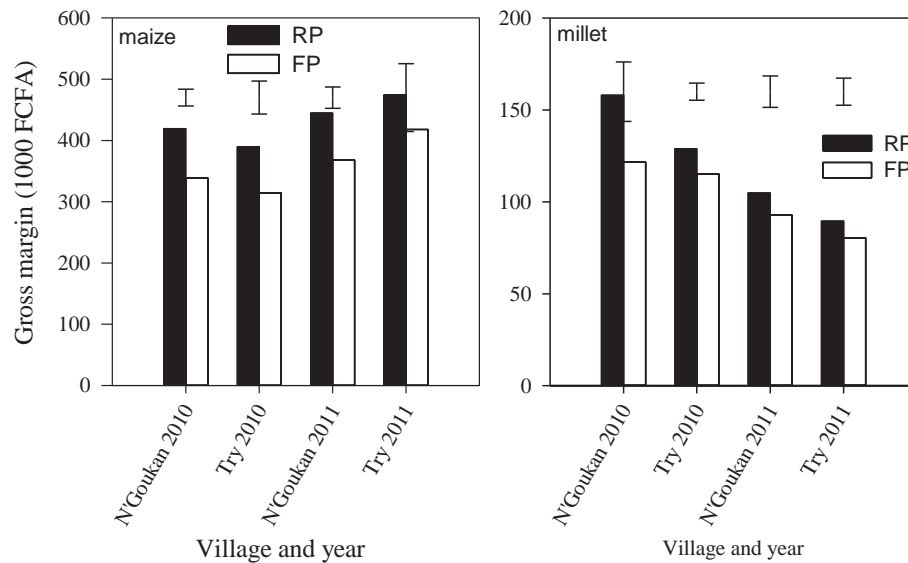


Fig 3.7: Gross margin of maize and millet with the Recommended Practice (RP) compared to Farmer Practice (FP) at Try and N'Goukan. Note the different scale of the y axis between the two graphs.

### 3.3.3. Farmer's evaluation of the experiments

Farmers attributed the performance of RP both with maize and millet to timely crop management (weeding and application of chemical fertilizer), which, according to them, was easy to achieve on the small experimental plots (Table 3.5). This means that yield can be increased through improved crop management, but that the feasibility of the tested adaptation options on larger areas depends on the availability of labour, inputs and equipment.

It was unanimously agreed that chemical fertiliser is the key factor for increasing maize and millet yield in the region. However, due to its high price, fertiliser is also a limiting factor, which is why farmers prioritize maize to receive fertilizer over the other cereals. Most farmers do not use chemical fertilizer on millet, because they think that millet can also yield without nutrient inputs. In the fields with the RP treatment, compound fertilizer was used at planting as recommended by the national agricultural research institute. However, this practice is costly and labour demanding and therefore not part of farmers' practice, which is geared to planting a large area in a short time. Instead, farmers prefer applying fertiliser at crop emergence as a climate risk management strategy. Indeed, later fertilisation saves resources in case of a long dry spell after planting or low germination rates due to poor seed quality. To some extent it also helps to schedule the use of available labour.

Farmers are aware of the negative effect of delaying planting of maize and millet on crop yields. However, in certain circumstances, such as equipment constraints or peak labour demands when the season starts late, they are forced to delay planting. An alternative solution in this situation would be to use short-duration varieties, which ensure at least a modest yield. Yield variability between farms was largely determined by the capacity of the household to apply proper cropping management. The main factors included timely ploughing when the soil is wet, timely planting and the application of chemical fertilizer on the recommended date. For instance, a farmer with no equipment (cart, plough) and lack of cattle will have to rely on others, which can cause a delay in cropping activities and lead to a poor response to actual weather conditions.

Table 3.5: Farmers’ evaluation of the experiment (Recommended Practice (RP) and Farmer Practice (FP))

| Result                                       | Farmers’ comments   | Lesson learned  |
|--|---|---|
| Maize yield with RP is greater than with FP  | Plots are small in size therefore easy to manage at required time   | Yields can be strongly improved through better cropping management        |
| Millet yield with RP is greater than with FP | Due to mineral fertiliser supplied<br>Millet can produce without any supplied fertiliser  | Farmers do not agree whether or not to supply fertiliser on millet        |
| Use of compound fertilizer at planting date  | Risk of crop burning in case of drought, risk of fertilizer loss in case of poor seed quality   | Plants germinate vigorously with fertilizer at planting                   |
| Yield decrease with delay in planting date   | The effect of planting date is known, but due to constraints related to the onset of the season, labor and equipment availability, and crop rotation decisions, planting can be delayed<br>Farmers were not interested in late planting after the first year experiment | An alternative solution in this situation is to use a short cycle variety |
| Yield variability from one field to another  | Depends on the landscape position of the field (foot slope, lower slope or upper slope) which determines inherent soil fertility.<br>Depends on the time the field has been cultivated, the fallow period and the nutrient input  | Management practice is the key factor                                     |
| Spatial variability of rainfall              | This was the first time that farmers used a rain gauge and could quantify and observe the spatial distribution of rainfall  | Farmers were eager to learn about weather observations                    |

### **3.4. Discussion**

#### **3.4.1. Farmers' perceptions of climate change and effects of weather anomalies on crop production**

Farmers identified the later start and earlier end of the rainy season, the decrease of annual rainfall and the increased occurrence of dry spells as key indicators of climate change. The perceived increase in the occurrence of unfavourable weather conditions was partly confirmed through an analysis of observed historical weather data in southern Mali (Traore et al., 2013), showing an increase in inter annual rainfall variability and the number of dry spells during the growing season. These results concur with those of Cooper et al. (2008) for sub-Saharan Africa. Significant relationships between observations and farmer perceptions of climate change were also found in several other countries (Apata et al., 2009; Deressa et al., 2009).

Although most farmers perceived a continuous decrease of annual rainfall, this was not confirmed by the analysis of the long-term climate data: no clear change in total precipitation was observed over the last five decades in southern Mali (Traore et al., 2013). That farmers think they experience a change in annual rainfall could be caused by the increase in the year to year variability of seasonal rainfall (Balme et al., 2006). Findings by Diggs (1991) support the hypothesis that changes in environmental variability are often accompanied by perceived changes in absolute terms. For temperature, farmers' perception of a substantial increase matches the empirical observations for the region well (Hulme et al., 2001). Farmers linked the temperature increase to a change in the number of dry days in the growing season, as these are perceived to be hot.

Climate variability is often given as the main reason for crop failure and food shortages (Mishra et al., 2008; Sultan et al., 2005). Irregular rainfall distributions may expose the crop to a range of mild to severe intra-seasonal water stresses, which may subsequently affect the yield especially if they occur during the critical stages of flowering and grain filling. This relation between weather anomalies and crop production was also acknowledged by the farmers in this study, as was the potential of various adaptation measures to cope with the unpredictable nature of the weather.

#### **3.4.2. Role of planting date as adaptation strategy**

The onset of the rainy season is the most important driver of agricultural management (Ingram et al., 2002; Stewart, 1991). It directly affects crop management practices, especially

planting date, which has a significant effect on crop yield. Our results indicate that the yield of maize and millet decreases when planting is delayed, suggesting an important role for timely planting in dealing with the year-to-year variability of the weather. Other studies have also shown that late planting of maize resulted in significant yield decreases (Kamara et al., 2009; Soler et al., 2008). To take advantage of early planting, farmers even conduct ‘dry planting’, which consists of planting before the rains start. This practice is used with millet and tends to ease the general labour shortage for land preparation and planting at the first rains. Early planting however can be risky, because of the occurrence of early-season dry spells. High soil temperatures associated with dry weather as well as scarce and erratic rainfall before the full installation of the rainy season may spoil the seeds (Graef and Haigis, 2001a) and affect the germination and establishment. However, Traore et al. (2014) indicated that there is a flexibility in the timing of planting in the Sudano-Sahelian region depending on the type of crop. The planting date of maize can be delayed up to 30 days from the first of June without significant yield loss. For millet, delayed planting will result in a smaller yield loss with short, non-photoperiod sensitive varieties than with long-duration varieties.

In many West African farming systems, farmers delay planting because of the free grazing of animals at the beginning of the season, which can cause significant damage to the establishing crop and because of bird damage, which may occur if the crop grain filling is out of phase with that of neighbouring crops (Andrews, 1973). Socio-economic and technical constraints also determine the choice of planting dates. Large farms with resources (plough and cattle) can usually take advantage of the first rains, while small farms are often delayed. Especially the availability of labour is a constraining factor at the time of land preparation and planting.

#### **3.4.3. Intensification as an option for adaptation to climate change**

Farmers’ evaluation of the experiment indicated that the size of farm fields plays an important role in the potential for intensification. The limited financial and labour resources of the family in comparison with the relatively large cropped area results in small rates of agricultural inputs and delays in cropping activities. Our results showed that by using the recommended rates of chemical fertilizer, the yield and gross margin of maize can be substantially increased. Farmers are aware of the importance of chemical fertilizer on maize but constrained by the limited access to input markets and financial resources.

Millet also yielded more when fertilizer was applied, but the gross margin did not improve significantly. The increase in yield is in agreement with the results of several other studies in

Sudano-Sahelian countries (Bationo et al., 1989; Pieri, 1989). Nitrogen application appears to increase straw yield when the rainy season starts early, while it always increases grain yield even at small rates, at least when no water stress occurs during the growing season (Bacci et al., 1999). The lack of responses in gross margin is caused by the relatively high cost of fertilizer in relation to the yield response of millet and the relatively poor price of millet grain. The local varieties of millet used by the farmers are characterized by poor but stable grain yields (Andrews, 1973). These varieties have a strong ability to adapt to environmental constraints such as striga or soil acidity (Bazile et al., 2008). The overall lack of gross margin response of millet supports the farmers’ preference to use fertilizer on maize: maize yields very little under nitrogen stress conditions, while millet always produces a modest yield even without any application of N.

Intensifying agriculture through increased nutrient application can be seen as an adaptation option to climate change, as resulting higher yields especially in favourable years, could provide options for grain storage and the evening out of crop failure risks related to year-to-year rainfall variability (Milgroom and Giller, 2013). Even though our study shows a larger grain yield improvement potential for maize than for millet, the storage capacity of maize is poorer than that of millet.

Furthermore, proper adaptation requires an integrated approach including proper planting windows for each crop (Traore et al., 2014) as there is an important interaction between fertilizer use efficiency and planting date. For both maize and millet, fertiliser application at late planting does not result in higher yields. Rurinda et al. (2013) also reported that with a substantial delay in planting, soil fertility management cannot compensate yield losses.

#### **3.4.4. Action to be taken to help smallholder farmer to deal with climate change and variability**

The current farmers’ understanding of climate and prediction of weather is mostly based on indigenous knowledge, which can be considered as a kind of legacy and heritage from the farmers’ forebears. For example, farmers predict a good rainy season by a shooting star coming from a particular direction, or heavy rains based on a strong wind and dark clouds from a particular direction. With current easy-to-use and cheap tools and technologies however, many opportunities exist to complement the indigenous knowledge with science-based observations and predictions.

The adaptation strategies tested in this study were focused on technical crop management aspects, but the successful dissemination and adoption of risk management strategies will

involve a variety of private initiatives, policy measures and institutions (Lybbert and Sumner, 2012). Crop management would benefit from extension and national weather services collaborating in the establishment of early warning systems and in the further improvement of the current climate predictions, resulting in information that is meaningful for local farmers. The growth in the use of mobile phones in rural Mali constitutes a new channel and new opportunities for accessing information, if it is supplied in the right way. The recent launch of the project ‘Senekela’ of the mobile company ‘Orange Mali’ is an initiative that aims at facilitating the access of farmers to information via the mobile phone. This approach needs to be scaled up to enable farmers to benefit from the variety of information relevant for each stage of the agricultural production process, ranging from weather forecasts, seed availability, fertilizers, to pest and disease management. Evidence from Kenya shows that it is possible to reach millions of farmers with climate services that support decision-making under a changing climate by using mobile phones (Aker, 2011). The ability to anticipate weather anomalies and prepare to mitigate their impact on agricultural production gives farmers the opportunity to better manage climate related risks (Hammer et al., 2001; Hansen et al., 2011). In the short term improved weather information increases the ability of farmers to take appropriate actions to face adverse weather events. It offers the opportunity to improve the timing and management of inputs in ways that reduce financial and production risks.

### **3.5. Conclusion**

Farmers are aware and conscious of climate change and variability and viewed it as a real risk to their livelihood. Their agricultural practices could be improved by use of forecasted weather data, enhancing the agility to tackle challenges posed by climate change and variability. Drought tolerant, short maturing crop varieties and appropriate planting were the commonly preferred adaptation strategies to year-to-year variability in the weather conditions. This strategy seems central to developing tactical and strategic measures to cushion farmers against the potential impact of climate change and increased climate variability. Use of chemical fertilizer is a better alternative to enhance the yield of maize, while for millet it is unprofitable. Yields can be increased through improved crop management, but the feasibility of options depends on the availability of labour, inputs and equipment. Training of farmers on weather and climate related aspects like the onset of rains is critical to inform decision making in agricultural production.



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**Chapter 4**

**Evaluation of climate adaptation options for Sudano-Sahelian cropping systems**

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### **Abstract**

In the Sudano-Sahelian region, smallholder agricultural production is dominated by rain-fed production of millet, sorghum and maize for food consumption and of cotton for the market. A major constraint for crop production is the amount of rainfall and its intra and inter-annual variability. We evaluated the effects of planting date on the yield of different varieties of four major crops (maize, millet, sorghum and cotton) over three contrasting growing seasons in 2009-2011 (with 842 mm, 1248 mm and 685 mm of rainfall respectively) with the aim of identifying climate adaptation options in the Sudano-Sahelian region. Three planting dates (early, medium, and late) and three varieties of long, medium, and short duration of each crop were compared.

For fertilized cereal crops, maize out yielded millet and sorghum by respectively 57% and 45% across the three seasons. Analysis of 40 years of weather data indicates that this finding holds for the longer time periods than the length of this trial. Late planting resulted in significant yield decreases for maize, sorghum and cotton, but not for millet. However, a short duration variety of millet was better adapted for late planting. When the rainy season starts late, sorghum planting can be delayed from the beginning of June to early July without substantial reductions in grain yield. Cotton yield at early planting was 28% larger than yield at medium planting and late planting gave the lowest yield with all three varieties. For all four crops the largest stover yields were obtained with early planting and the longer planting was delayed, the less stover was produced. There was an interaction between planting date and variety for millet and sorghum, while for maize and cotton the best planting date was more affected by the weather conditions. The findings of this study can support simple adaptation decisions: priority should be given to planting cotton early; maize is the best option if fertilizer is available; planting of maize and sorghum can be delayed by up to a month without strong yield penalties; and millet should be planted last.

**Key words:** Planting date, maize, sorghum, pearl millet, cotton, rainfall, West Africa.

#### 4.1. Introduction

The economy and food security of the rural population are strongly dependent on farming in the Sudano-Sahelian countries. Rain-fed agriculture produces nearly 90% of food and feed, and is the major livelihood activity for 70% of the population (Club du Sahel, 2011). In Mali, cereal production increased over the last two decades from 1.9 million tons in 1990/1 to 4.1 million tons in 2008/9, which corresponds to an annual increase of 4.6% (Staatz et al., 2011). On the other hand, cotton (*Gossypium hirsutum* L.) is responsible for the largest share of foreign currency revenues from agriculture in Mali (Deveze, 2006; Nubukpo and Keita, 2006). The income from cotton finances much of the rural infrastructure, literacy programmes for farmers, and funding for farmer organizations and extension programs. Producing cotton also gives farmers access to chemical fertilizer and other inputs that are provided on credit by the cotton companies. Some of the fertilizer obtained on credit is diverted for the production of maize (*Zea mays* L.). Moreover, maize and other cereals, grown in rotation with cotton, benefit from the residual effects of the fertilizer used on cotton (Piéri, 1989).

The most important cereals grown in Mali in terms of both area cropped and total production are millet (*Pennisetum glaucum* (L.) R.Br.) and sorghum (*Sorghum bicolor* (L.) Moench). The production of millet and sorghum increased, respectively, by 3.4 and 1.3% per year over the period 1990-2009, from 736 400 t yr<sup>-1</sup> for millet and 634 600 t yr<sup>-1</sup> for sorghum in 1990. This increase was mainly due to land expansion rather than to an increase in yields per ha. The cropping area increased respectively by 2 and 0.5 % per year for millet (from 111 600 ha in 1990) and sorghum (from 816 400 ha in 1990). Average grain yield of millet went up from 662 to 797 kg ha<sup>-1</sup>, an increase of 1.3% per year, while that of sorghum went up from 797 to 901 kg ha<sup>-1</sup>, an increase of 0.9% per year. During the last two decades, however, the production of maize has become more important. It increased from 215 300 t yr<sup>-1</sup> in 1990 to 697 200 t yr<sup>-1</sup> in 2009 with an annual increase of 6.7%. Meanwhile, the average maize grain yield rose from 1181 to 1790 kg ha<sup>-1</sup> with an annual increase of 2.3%. (Staatz et al., 2011).

Cropping systems in the Sudano-Sahelian zone are characterized by low productivity due to erratic rainfall, poor soil fertility, and poor crop management with few external inputs (Voortman et al., 2004). Cotton and to a lesser extent maize, receive nutrient inputs in the form of organic manure and/or chemical fertilizer. Other cereal crops seldom receive any fertilizer. As a consequence, soils are mined and soil organic matter contents decline (Piéri, 1989). The main cash crops, maize and cotton, are more demanding in terms of labour and fertilizer inputs, and not all farmers can afford these. Therefore, to be less dependent on

external inputs and to ensure production of the minimum food needs of the family, farmers rely on local varieties of the traditional crops, millet and sorghum, that continue to produce without the use of chemical fertilizer (Soumare, 2008).

The capacity of the cropping systems to support local food security depends to a large extent on the seasonal patterns of rainfall, which vary strongly between years (Sultan et al., 2005; Sultan and Janicot, 2003). Seasonal rainfall amount, intra-seasonal rainfall distribution and dates of onset/cessation of the rains influence crop yields and determine the agricultural calendar (Maracchi et al., 1993; Sivakumar, 1988). The rainy season is short and varies in length, with the number of rainy days varying from year to year (Traore et al., 2013). High evaporation losses (up to 50% of annual rainfall) and a dominance of sandy soils with low water holding capacity, result in soil water shortage during the growing season, when rains are erratic (Rockstrom, 1995).

Risk avoiding strategies become more pertinent, but also challenging when future climate projections of the Sudano-Sahelian region are taken into account. The region is likely to get hotter as a result of global warming (Butt et al., 2006). High temperatures occurring in combination with drought (Rahman, 2006), will lead to increased crop water stress and therefore cause scalding in cereals (Burke, 1990), disturb flowering and strongly reduce crop yields (Fisher et al., 1997; Mackill et al., 1982; Zheng and Mackill, 1982).

Choosing the appropriate planting date is important for maximizing cereal grain yields because optimum planting dates favour the establishment of healthy and vigorous plants (Egharevba, 1979). Generally, the planting time coincides with the first substantial rains of the season in order to optimize yields of both grain and straw (Egharevba, 1979). However, due to the erratic rainfall pattern in the Sudano-Sahelian regions, the first rain suitable for planting is often followed by several dry days that may cause the planting to fail and oblige the farmer to re-plant. Delayed planting can avoid this problem, but late planting results in a substantial shortening of the growing season and, consequently, in lower yields. Another constraint related to the planting date is the availability of labour, especially at the beginning of the rainy season. Lack of or insufficient labour can hinder the capacity of the farmer to prepare the soil, thereby causing a delay in the planting date.

Crop management practices based on adjusting the planting date and choice of variety are the adaptation strategies most readily available to farmers to deal with the effects of climate variability, but quantitative information for these options is scant for the Sudano-Sahelian region. Our aim was to fill this gap with quantitative data, and to evaluate experimentally the effects of different planting dates on the yield of different varieties of the major crops (maize,

millet, sorghum and cotton) over three contrasting growing seasons in southern Mali, at a location representative of the Sudano-Sahelian region. The experimental results together with a long-term rainfall dataset were used to identify adaptation options for the Sudano-Sahelian cropping systems.

## 4.2. Materials and methods

### 4.2.1 Study area and experiment

A field experiment was carried out during three consecutive growing seasons (from 2009 to 2011) at the agricultural research station of N'Tarla (12°35'N, 5°42'W 302 m. a. s. l.) in southern Mali. The climate at N'Tarla is typical of the Sudano-Sahelian region. The region has a mono-modal rainfall pattern with a distinct rainy season (May–October) of about 850 mm yr<sup>-1</sup> on average (1965–2005). The mean temperature is 29 °C, with peaks of up to 36 °C. The soil of the experimental site is a Ferric Lixisol (FAO, 2006) with 4%, 16% and 80% clay, silt and sand content in the top soil of 40 cm. The soil is slightly acid with a pH of 5.6 resulting in high aluminium toxicity (Hazelton and Murphy, 2007). The organic C content (2 g kg<sup>-1</sup>) is slightly below the average value (3 to 5 g kg<sup>-1</sup>) for the Sudano-Sahelian region (Veldkamp et al., 1991). Available P (11 mg kg<sup>-1</sup>) is slightly above the critical level of 8 mg kg<sup>-1</sup> that was established for cereal crops in the region (Bationo et al., 1989).

The farming systems in the study region are mixed crop-livestock systems, with cotton as the main cash crop in rotation with cereals – sorghum, millet, maize – and legumes – groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* (L.) Walp.). Only cotton and maize receive nutrient inputs in the form of manure and/or chemical fertilizer, as well as pesticides. Other cereal crops seldom receive any chemical inputs or manure. Crop residues are principally used for feeding livestock during the dry season (Powell et al., 2004; Sere and Steinfeld, 1996). Livestock provides draught power for tillage, crop planting, weeding, and transport of crop harvests, and produces meat and milk for the households thereby generating a cash income that is often invested in crop production. Furthermore, livestock is for farmers also a means of storing capital, buffering food shortages in years of poor crop production by selling off some of the livestock, and meeting social and religious obligations (Powell et al., 2004).

#### 4.2.2. Experimental design

The experimental design was a split-split-plot arrangement with three treatments and four replicates. The treatment on the main plots was the type of crop (maize, pearl millet sorghum, and cotton). On the sub-plots three open pollinated varieties of each crop were tested, referred to as V1 (long duration variety), V2 (medium duration variety), V3 (short duration variety) (Table 4.1) (FAO, 2008c). Varieties were selected from those produced and disseminated by the national seed company and grown by farmers. Three planting dates were chosen to cover the possible range of planting dates in southern Mali, referred to as D1 (early planting date), D2 (medium planting date) and D3 (late planting date) (Table 4.2). The treatments were randomized at crop and variety level but not for planting date because this was not logistically feasible for field operations such as weeding. In 2009, planting dates were slightly later than in 2010 and 2011 because of late rains. Plot size was 34 m<sup>2</sup> with 7 plant rows of 6 m length each.

#### 4.2.3. Crop management

Three tons per hectare of cattle dry manure (with organic matter content of 44%) were applied on all plots before ploughing. Each crop received the recommended mineral fertilizer rates (IER/CMDT/OHVN, 1998). Each year, 21 kg P ha<sup>-1</sup> of rock phosphate was applied to the cotton plots and 10 kg P ha<sup>-1</sup> to the cereals (maize, sorghum and millet) at planting. In addition, compound fertilizer NPK (14-22-12 for cotton and 16-16-16 for cereals) was used at planting, while urea (46% N) was used at 40 days after planting. In total, cotton received 44 kg of N ha<sup>-1</sup>, 54 kg of P ha<sup>-1</sup> and 18 kg of K ha<sup>-1</sup> and maize received 85 kg of N ha<sup>-1</sup>, 26 kg of P ha<sup>-1</sup> and 16 kg of K ha<sup>-1</sup>, while sorghum and millet received 39 kg of N ha<sup>-1</sup>, 26 kg of P ha<sup>-1</sup> and 16 kg of K ha<sup>-1</sup>. Plant densities for millet and sorghum were fixed at 50 000 plants ha<sup>-1</sup> with 0.8 m between rows and with two plants per hole at 0.5 m distance within rows. Planting density for cotton and maize was 83 333 and 62 500 plants ha<sup>-1</sup>, respectively. The inter-row distance for these crops was 0.8 m, with a within-row plant distance of 0.3 m for cotton and 0.4 m for maize. All crops were thinned (2 plants / hole) at 15 days after planting to achieve the above densities. Two to three weeding operations were done manually by hoeing. Cotton bolls were protected against pests, mainly *Helicoverpa armigera*, using the standard recommendations of 5–6 sprays, i.e. one every two weeks starting at 45 days after planting. Recommended products were applied, i.e. pyrethroids in the first two treatments and organophosphorus pesticides in the last three to four treatments.

Table 4.1: Characteristics of the crop varieties

| Crop    | Local name    | Selected name | Breeder institute | Potential yield (t ha <sup>-1</sup> ) | Duration (days) | Height (cm) | Cultivar codification | Photoperiod sensitivity |
|---------|---------------|---------------|-------------------|---------------------------------------|-----------------|-------------|-----------------------|-------------------------|
| Maize   | Sotubaka      | Suwan 1 – SR  | CIMMYT/IITA       | 7                                     | 110 – 120       | 250-300     | V1                    | none                    |
| Maize   | Dembagnuman   | Obatanpa      | CIMMYT/CRI        | 4-5                                   | 105 – 110       | 175         | V2                    | none                    |
| Maize   | Zangueréni    | Zangueréni    | IER               | 2                                     | 80              | 200-250     | V3                    | none                    |
| Millet  | M9D3          | M9D3          | IER               | 3                                     | 125 - 130       | 350-400     | V1                    | high                    |
| Millet  | Toroniou      | Toroniou C1   | IER               | 2                                     | 100 - 110       | 250-300     | V2                    | low                     |
| Millet  | Sossat        | Sossat c-88   | ICRISAT/IER       | 2.5                                   | 90              | 130-180     | V3                    | low                     |
| Sorghum | Soumalemba    | IS15-401      | CIRAD/ICRISAT     | 2                                     | 145             | 440         | V1                    | high                    |
| Sorghum | Jigui Seme    | CSM 388       | IER               | 2.5                                   | 125             | 370         | V2                    | medium                  |
| Sorghum | Jakumbe       | CSM 63E       | IER               | 2                                     | 100             | 200         | V3                    | low                     |
| Cotton  | STAM 59 A     | STAM 59 A     | IER               | 1.6                                   | 120-140         | 157         | V1                    | none                    |
| Cotton  | NTA 93-15     | NTA 93-15     | IER               | 1.4                                   | 130             | 135         | V2                    | none                    |
| Cotton  | N'TA93-15-ITK | N'TA93-15-ITK | IER               | 2                                     | 120-130         | 129         | V3                    | none                    |

(Source FAO, 2008)

Table 4.2: Cropping operations of the three varieties at three planting dates from 2009 - 2011 at NTarla agricultural research station, southern Mali

|  | 2009     |           |          | 2010     |           |         | 2011     |           |         |
|--|----------|-----------|----------|----------|-----------|---------|----------|-----------|---------|
|  | Early D1 | Medium D2 | Late D3  | Early D1 | Medium D2 | Late D3 | Early D1 | Medium D2 | Late D3 |
| Soil sample and manure                     | 12-13/05 | 12-13/05  | 12-13/05 | 5/15     | 5/15      | 5/15    | 5/30     | 5/30      | 5/30    |
| Ploughing                                  | 6/6      | 6/6       | 6/6      | 5/15     | 5/15      | 5/15    | 5/30     | 5/30      | 5/30    |
| Planting and compound fertilizer           | 6/12     | 7/2       | 8/4      | 5/31     | 7/1       | 8/2     | 6/1      | 7/1       | 8/1     |
| Thinning                                   | 7/1      | 7/17      | 8/18     | 6/23     | 7/14      | 8/18    | 6/23     | 7/19      | 8/16    |
| Nitrogen fertilizer                        | 7/15     | 8/4       | 8/18     | 7/12     | 7/30      | 8/19    | 7/11     | 8/10      | 8/16    |
| Number of weeding                          | 1/3      | 1/2       | 1/2      | 1/4      | 1/3       | 1/2     | 1/2      | 1/2       | 1/2     |
| Mounding                                   | 7/30     | 8/18      | 8/18     | 7/12     | 8/20      | 9/16    | 7/19     | 8/15      | 9/15    |
| Number of pesticide applications on cotton | 6        | 5         | 4        | 6        | 5         | 4       | 6        | 5         | 3       |

Precautions were taken to minimize bird attacks during the period from grain filling to maturity through the presence of two guards in the field.

#### **4.2.4. Measurements**

For all crops, the date of flowering was recorded when the first white flower (cotton), flowering panicle (millet, sorghum) or tassel (maize) appeared on 50% of the plants. Crops were harvested after physiological maturity; stover and grain yields were estimated from a net plot of 12 m<sup>2</sup> (3 rows of 5 m length) in the centre of the plot to avoid border effects. In the case of the cereals, grain was separated from stover. Stover and grain sub-samples for each treatment were bagged, weighed and oven-dried at 70 °C for 2 days to convert fresh weight to dry matter. Cotton was harvested in two stages as bolls matured, and weighed after sun drying for 3 days. Bolls were separated from stems and branches. Sub-samples of stems, branches and bolls were weighed, and oven-dried at 70 °C for 2 days to convert fresh weight to dry matter. Daily rainfall was recorded at the N'Tarla meteorological station situated at about 1 km from the experiment.

#### **4.2.5. Statistical analyses**

First the main effects of year and type of cereal crop (maize, millet and sorghum) were analysed using analysis of variance (ANOVA) procedures for a split-split plot design (GenStat Edition 14 Library Release PL18.2, VSN International Ltd). Year and cereal crop type were chosen as main factors, planting date as plot factor and variety as subplot factor. Separate ANOVA tests per crop were conducted to assess the effects of planting date and variety on cereal grain and seed cotton yield, and on stover yields. Main effects and interaction effects were considered as significant at a probability level of  $\leq 0.05$ . Tests for Pearson correlation were performed between yields of maize, millet, sorghum and cotton and the rainfall amounts recorded between planting and harvest date.

### **4.3. Results**

#### **4.3.1. Inter-annual rainfall variability, rainfall distribution and its relation with crop yields**

Overall, 60 to 70% of total rain occurred between July and September (Fig4.1). 2010 was the wettest year with 1248 mm, whilst the least rainfall was recorded in 2011 with 685 mm. The distribution of rainfall also varied from year to year. In 2011, a 13 day dry period occurred in



June, while in 2010 the first ten days of July 2010 received little rain. The end of the rainy season was very dry in 2011, with only 16 mm of rain in October against 123 mm and 168 mm in 2009 and 2010, respectively.

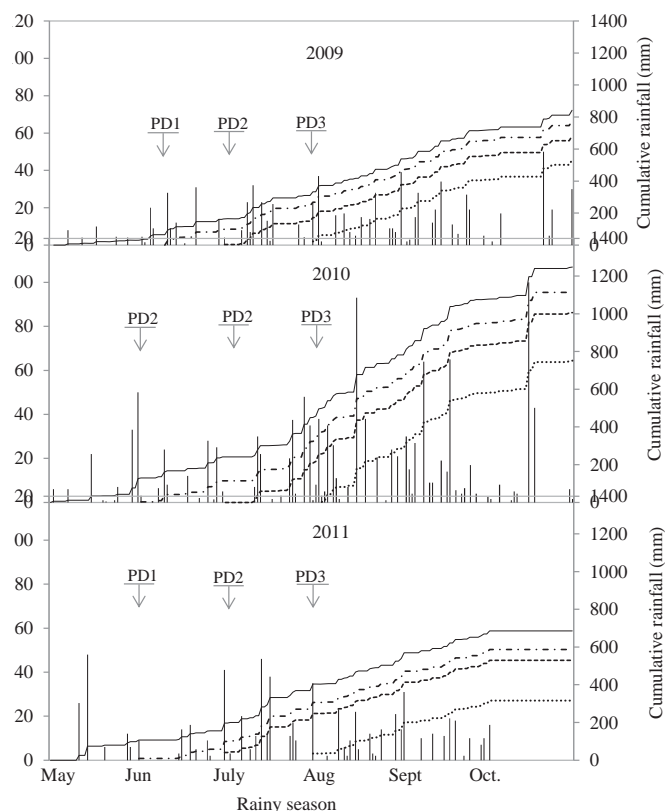


Fig 4.1: Daily and cumulative rainfall for 2009, 2010 and 2011 at N'Tarla agricultural research station, southern Mali. PD1= Planting date 1; PD2= Planting date 2; PD3= Planting date 3.

The correlation of grain yield of millet and sorghum with seasonal rainfall recorded from planting to harvest was not significant ( $P > 0.05$ ) while it was significant ( $P < 0.05$ ) for maize and cotton (Fig 4.2). There was also a significant positive correlation between seasonal rainfall and stover yields of maize and cotton. The correlation was significant for stover yield of sorghum only at  $P = 0.07$  and for millet at  $P = 0.10$ .

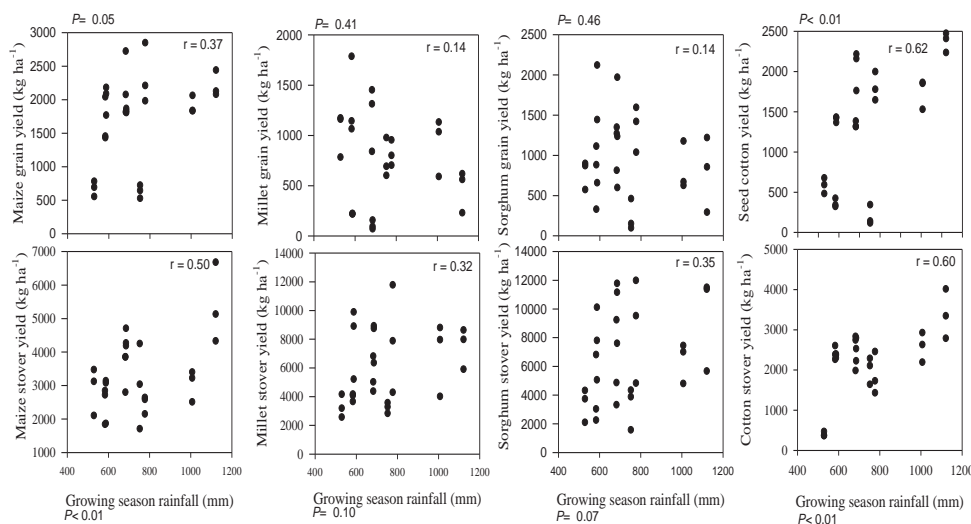


Fig 4.2: Scatter plots of grain yield, seed cotton, stover and growing season rainfall (mm) from planting to harvest for three years (2009 - 2011) at N'Tarla agricultural research station, southern of Mali. The points represent the average of the 4 replicates, by 3 seasons x 3 planting dates x 3 varieties.

#### 4.3.2. Analysis of cereal grain yields

The largest observed grain yield across the three years was for maize with 1721 kg ha<sup>-1</sup> (Table 4.3). It was significantly greater ( $P<0.003$ ) than the yields of millet and sorghum by 57% and 45% respectively. Grain yields of millet and sorghum did not differ significantly (Table 4.3). The largest cereal yields were observed with early planting date (D1) and medium planting date (D2), which were similar, and significantly greater (33%) than cereal yields at late planting (D3) (Table 4.3). Yields in 2009 were significantly larger than in 2010 and 2011.

Table 4.3: Main effect of year, crop and planting date on cereal grain yield (kg ha<sup>-1</sup>) over the period 2009 – 2011 at NTarla agricultural research station in southern Mali.

|                  | Year  |      |      | Crop  |        |         | Date     |           |         |
|------------------|-------|------|------|-------|--------|---------|----------|-----------|---------|
|                  | 2009  | 2010 | 2011 | Maize | Millet | Sorghum | Early D1 | Medium D2 | Late D3 |
| Yield            | 1425  | 974  | 1040 | 1721  | 764    | 954     | 1246     | 1317      | 876     |
| <i>P. Value.</i> | 0.001 |      |      | 0.003 |        |         | 0.001    |           |         |
| SED              | 55    |      |      | 174   |        |         | 51       |           |         |

There was a significant interaction of crop by year on grain yield over the 3 years ( $P<0.001$ ). Yield of maize was significantly larger than those of millet and sorghum in each of the three

years (Fig 4.3). Yields of millet and sorghum were similar; the analysis showed no significant difference in 2009 and 2010 whereas in 2011 sorghum yielded 697 kg ha<sup>-1</sup> more than millet. The analysis of the interaction of crops by planting date indicated that at D1 and D2, grain yield of maize, millet and sorghum were significantly different (Fig 4.3); yield of maize was larger than yields of both sorghum and millet. During the three experimental years, yield of sorghum and millet varied with planting date. At D1 sorghum grain yield was significantly larger than that of millet, whereas at D2 yields of both crops were similar except in 2011. At D3, sorghum yielded less than millet and maize. On the whole, yield of maize and sorghum decreased less with the delay from D1 to D2 than from D2 to D3. In contrast, yield of millet was systematically smaller at D1 whereas yields at D2 and D3 were similar. The analysis of the interaction of crop by variety indicated that the grain yields of all three maize varieties were significantly larger than those of sorghum and millet which were similar in 2009 and 2010 (Fig 4.3). However, in 2011 varieties V1 and V2 of sorghum performed better than the varieties of millet.

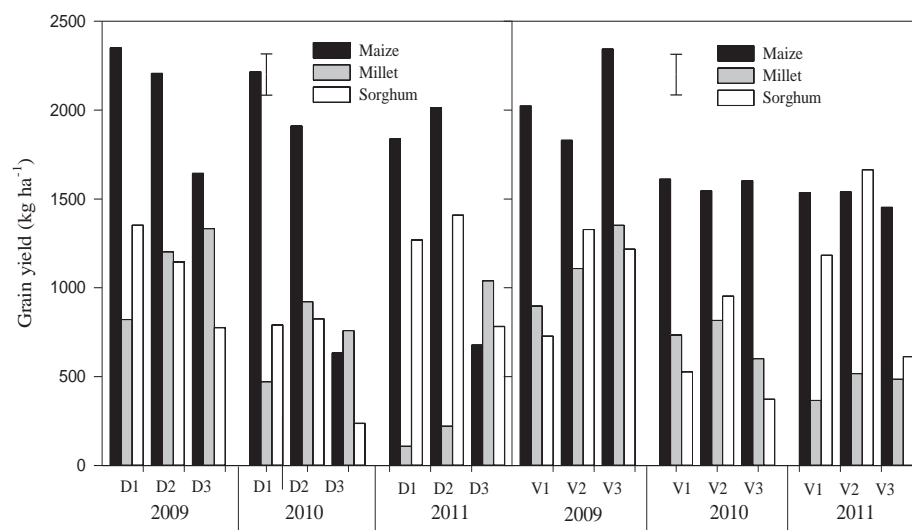


Fig 4.3: Cereal grain yield (maize, millet and sorghum) by planting date and variety for the three years of the experiment at NTarla agricultural research station, southern of Mali. D1= Early planting, D2= medium planting, D3= late planting, V1= Long duration variety, V2=medium duration variety, V3= short duration variety. The bar represent Standard Error of Difference of mean for the interaction of crop\*year\*planting date and crop\*year\*variety.

### 4.3.3. Effect of varieties and planting date on grain yield, harvest index and stover yield

#### Maize

##### Maize grain yield

The largest grain yield of maize was obtained in 2009 (Table 4.4). It was 25% larger than the yields obtained in 2010 and 2011, which were similar. Across the three years, yields obtained with early planting (D1 and D2) were about 50% larger than with late planting (D3). No significant differences between varieties were found. The interaction of variety by planting date had no significant effect on maize grain yield (Fig 4.4). In 2010 and 2011 and for all varieties, yields at D1 and D2 were similar and significantly larger than that at D3.

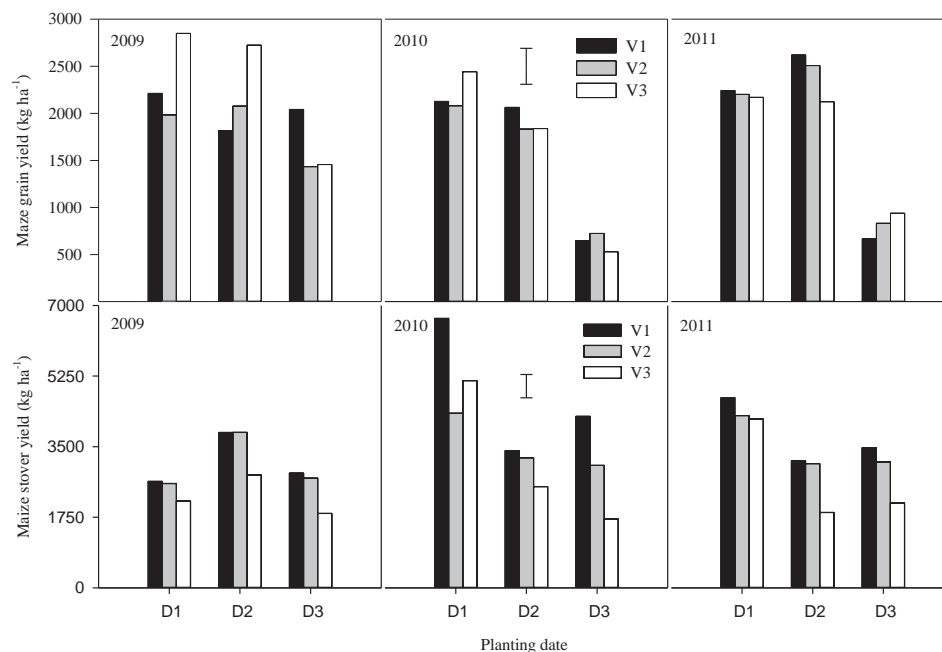


Fig 4.4: Maize grain and stover yield ( $\text{kg ha}^{-1}$ ) for three planting dates and three varieties for the three years of the experiment at N'Tarla agricultural research station, southern Mali. D1 = Early planting, D2 = medium planting, D3 = late planting, V1 = Long duration variety, V2 = medium duration variety, V3 = short duration variety. The bar represent Standard Error of Difference of mean for the interaction of year\*planting date \*variety.

***Maize stover yield, harvest index and time to flowering***

The largest stover yield across varieties and planting dates was obtained in 2010 with an average of 3808 kg ha<sup>-1</sup> (Table 4.4). This was 26% and 13% larger than stover yields obtained in 2009 and 2011, which were not significantly different. Across the three years, there were significant differences in stover yield depending on planting date: D1 with 4076 kg ha<sup>-1</sup> outperformed D2 and D3 by respectively 24% and 32%. The largest stover yield was obtained with V1 (3888 kg ha<sup>-1</sup>) which was significantly greater by 14% and 33% than that obtained with V2 and V3. The interaction effects of planting date by year on maize stover yield were significant, while interactions of variety by year and planting date by variety were not (Table 4.4). The large grain yield of maize in 2009 was partly due to a high harvest index, whereas in 2010 the highest crop biomass was measured while the harvest index was low. The harvest index of V3 was significantly higher than that of V1 and V2, which were similar.

The time to flowering of maize did not change significantly with change of planting date. For the three varieties, V3 flowered earlier than V1 and V2, which had similar time to flowering (Table 4.5).

## Chapter 4 – Evaluation of climate adaptation options for Sudano – Sahelian cropping systems

Table 4.4: Effect of planting dates, varieties and year and their interactions on yield, biomass (kg ha<sup>-1</sup>) and harvest index of maize, millet sorghum and cotton over the period 2009-2011 at NTarla agricultural research station in southern Mali

|                 | Maize        |              |               | Millet       |              |               | Sorghum      |              |               | Cotton       |              |               |
|-----------------|--------------|--------------|---------------|--------------|--------------|---------------|--------------|--------------|---------------|--------------|--------------|---------------|
|                 | Grain yield  | Stover yield | Harvest index | Grain yield  | Stover yield | Harvest index | Grain yield  | Stover yield | Harvest index | Grain yield  | Stover yield | Harvest index |
| 2009            | 2066         | 2809         | 0.42          | 1119         | 5787         | 0.16          | 1091         | 6211         | 0.15          | 1170         | 2270         | 0.34          |
| 2010            | 1587         | 3808         | 0.29          | 717          | 5889         | 0.11          | 618          | 6401         | 0.09          | 1442         | 2659         | 0.35          |
| 2011            | 1510         | 3328         | 0.31          | 456          | 6444         | 0.07          | 1153         | 7079         | 0.14          | 1347         | 1756         | 0.43          |
| <i>P. value</i> | <i>0.001</i> | <i>0.001</i> | 0.001         | <i>0.001</i> | <i>0.243</i> | 0.003         | <i>0.001</i> | <i>0.071</i> | 0.003         | <i>0.074</i> | <i>0.001</i> | 0.001         |
| SED             | 137.9        | 192.1        | 0.02          | 45.4         | 414.9        | 0.015         | 70.5         | 386.4        | 0.021         | 117.9        | 156          | 0.02          |
| Early (D1)      | 2134         | 4076         | 0.34          | 467          | 7838         | 0.06          | 1137         | 9496         | 0.11          | 2077         | 2591         | 0.44          |
| Medium (D2)     | 2044         | 3081         | 0.40          | 781          | 6781         | 0.10          | 1127         | 6632         | 0.15          | 1499         | 2485         | 0.38          |
| Late (D3)       | 985          | 2789         | 0.26          | 1044         | 3502         | 0.23          | 599          | 3563         | 0.14          | 383          | 1610         | 0.19          |
| <i>P. value</i> | <i>0.001</i> | <i>0.001</i> | 0.001         | <i>0.001</i> | <i>0.001</i> | 0.001         | <i>0.001</i> | <i>0.001</i> | 0.953         | <i>0.001</i> | <i>0.001</i> | 0.001         |
| SED             | 116.6        | 205.1        | 0.01          | 70.4         | 368.4        | 0.020         | 71.6         | 410.3        | 0.035         | 143.6        | 214          | 0.03          |
| Long (V1)       | 1724         | 3888         | 0.31          | 666          | 7294         | 0.08          | 813          | 8450         | 0.09          | 1331         | 2453         | 0.35          |
| Medium (V2)     | 1639         | 3357         | 0.33          | 813          | 6372         | 0.11          | 1315         | 7104         | 0.16          | 1279         | 2099         | 0.38          |
| Short (V3)      | 1800         | 2701         | 0.40          | 813          | 4455         | 0.15          | 734          | 4137         | 0.15          | 1349         | 2134         | 0.39          |
| <i>P. value</i> | <i>0.159</i> | <i>0.001</i> | 0.001         | <i>0.211</i> | <i>0.001</i> | 0.198         | <i>0.001</i> | <i>0.002</i> | 0.462         | <i>0.561</i> | <i>0.17</i>  | 0.16          |
| SED             | 71.5         | 169.1        | 0.02          | 84.3         | 362.6        | 0.028         | 60.8         | 702.0        | 0.029         | 63.7         | 178          | 0.03          |
| Date*year       | 0.049        | 0.001        | 0.03          | 0.001        | 0.024        | 0.029         | 0.329        | 0.098        | 0.046         | 0.045        | 0.001        | 0.04          |
| Date*variety    | 0.517        | 0.128        | 0.02          | 0.022        | 0.004        | 0.040         | 0.074        | 0.003        | 0.057         | 0.96         | 0.910        | 0.05          |
| Variety*year    | 0.472        | 0.129        | 0.03          | 0.001        | 0.334        | 0.035         | 0.001        | 0.037        | 0.042         | 0.96         | 0.119        | 0.04          |

Table 4.5: Time (days) from planting to flowering for maize, millet, sorghum and cotton in the trial at NTarla agricultural research station in southern Mali. Values represent average of 2009, 2010 and 2011 The P-value represents the significance of the difference of flowering time for the early, medium and late planting date for each variety of each crop.

|                 | Maize        |           |         | Millet       |           |         | Sorghum      |           |         | Cotton       |           |         |
|-----------------|--------------|-----------|---------|--------------|-----------|---------|--------------|-----------|---------|--------------|-----------|---------|
|                 | Early D1     | Medium D2 | Late D3 | Early D1     | Medium D2 | Late D3 | Early D1     | Medium D2 | Late D3 | Early D1     | Medium D2 | Late D3 |
| Long (V1)       | 57           | 53        | 57      | 91           | 75        | 60      | 138          | 108       | 88      | 57           | 58        | 59      |
| <i>P. value</i> | <i>0.120</i> |           |         | <i>0.001</i> |           |         | <i>0.001</i> |           |         | <i>0.080</i> |           |         |
| Medium (V2)     | 56           | 55        | 55      | 85           | 65        | 56      | 109          | 87        | 70      | 58           | 58        | 58      |
| <i>P. value</i> | <i>0.130</i> |           |         | <i>0.001</i> |           |         | <i>0.001</i> |           |         | <i>0.810</i> |           |         |
| Short (V3)      | 50           | 49        | 49      | 64           | 63        | 59      | 74           | 67        | 58      | 56           | 58        | 59      |
| <i>P. value</i> | <i>0.040</i> |           |         | <i>0.120</i> |           |         | <i>0.001</i> |           |         | <i>0.060</i> |           |         |

## Millet

### Millet grain yield

Millet grain yields, across planting dates and varieties were significantly different between years (Table 4.4). Yields obtained in 2009 were greater than those obtained in 2010 and 2011. Across the years, the largest yield was obtained at D3 which was significantly larger than at D2 and both were significantly greater than yield at D1. There was no significant difference between the three varieties.

During the three years, V3 had clearly larger yields with late planting (D3) indicating that this variety is better adapted to late planting conditions (Fig 4.5). For V2, the best yield was obtained at D2, except in 2011. The interaction between year and variety indicated that in 2009 the largest yield was obtained with V3, while in 2010 and 2011 V2 yielded most. The analysis of the interaction of planting date by year showed that, in 2010, millet yield at D2 was significantly larger than that at D3, but in 2011 the opposite was observed.

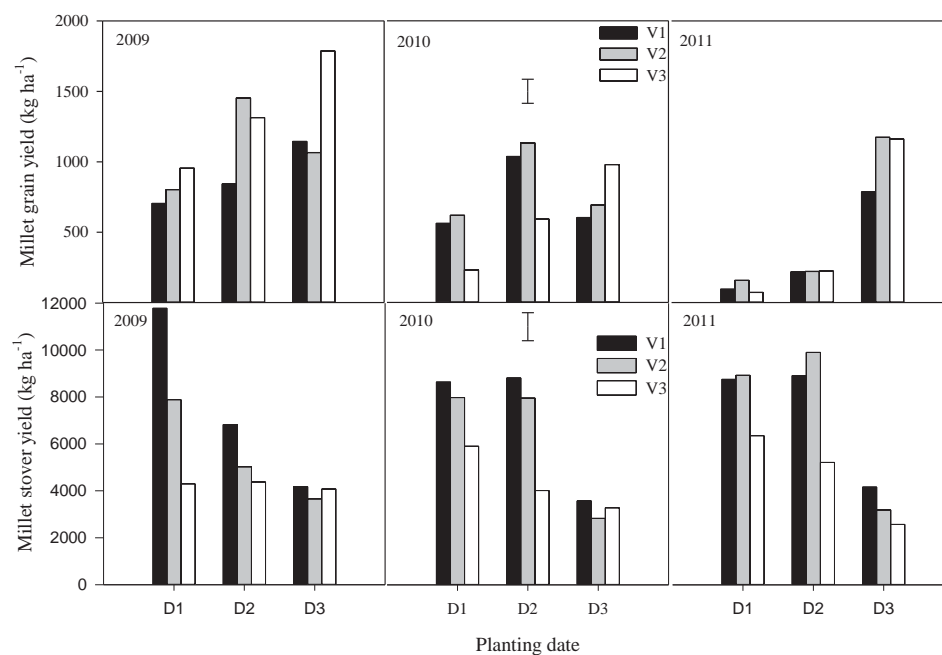


Fig 4.5: Millet grain and stover yield ( $\text{kg ha}^{-1}$ ) for three planting dates and three varieties for the three years of the experiment at N'Tarla agricultural research station, southern Mali. D1 = Early planting, D2 = medium planting, D3 = late planting, V1 = Long duration variety, V2 = medium duration variety, V3 = short duration variety. The bar represent Standard Error of Difference of mean for the interaction of year\*planting date\*variety.

***Millet stover yield, harvest index and time to flowering***

Across varieties and planting dates, there was no significant difference between stover yield recorded over the three years ( $P=0.24$ ) (Table 4.4), while across the three years, there was a significant decrease with the delay in planting date. The largest stover yield was obtained with V1, which was significantly larger than stover obtained with V2 and V3 (Table 4). Interaction effects of variety by planting date resulted in stover yields of V1 and V2 being larger than that of V3 for D1 and D2 but similar for D3 (Fig 4.5). The harvest index increased progressively from D1 to D3 for all three varieties in any given year (Table 4.5). V3 had the largest harvest index, despite its low biomass production. The duration of the period from planting to flowering of millet (Table 4.5) was significantly reduced with the delay of planting date for V1 and V2 but not for V3.

***Sorghum***

***Sorghum grain yield***

Across varieties and planting dates, the largest grain yield of sorghum was obtained in 2011 which was similar to the yield obtained in 2009 (Table 4.4). Both yields were significantly larger than the yield in 2010. Across the three years, the largest yield was obtained at D1 which was similar to the yield at D2, but both were significantly larger than yield at D3. Yield of V2 was significantly larger than that of V1 and V3.

The analysis of the interaction effect of variety by planting date on yield of sorghum (Fig 6) over the three years indicated a significant decrease of sorghum yield with planting date for the three varieties in 2009. This trend was less obvious in 2010 and 2011, although still observed for V1 in 2010. A decrease in yield from D2 to D3 was observed for all years and all varieties. Interaction of variety by year was also significant (Table 4.4). It indicated that the best yield obtained within the three years was with V2. In addition, yield of V3 was significantly greater than yield of V1 in 2009, but in 2010 and 2011 the opposite was found.

***Sorghum stover yield, harvest index and time to flowering***

Stover yield during the three years was similar but with a clear decrease associated with a delay in planting date across the three varieties (Table 4.4). Stover yield of V1 was significantly larger than that of V2 and V3. Interaction of variety by planting date indicated a significant decrease in stover yield with later planting date during each of the three years and for all varieties (Fig 4.6). The harvest indices observed 2009 and 2011 were significantly larger than in 2010. Across the three years, there were no significant differences in harvest



index between planting dates or varieties (Table 4.4). The duration from planting to flowering of sorghum decreased significantly with the delay in planting date and for all of the three varieties. The shortening of the period to flowering was largest for V1 followed by V2 and smallest for V3.

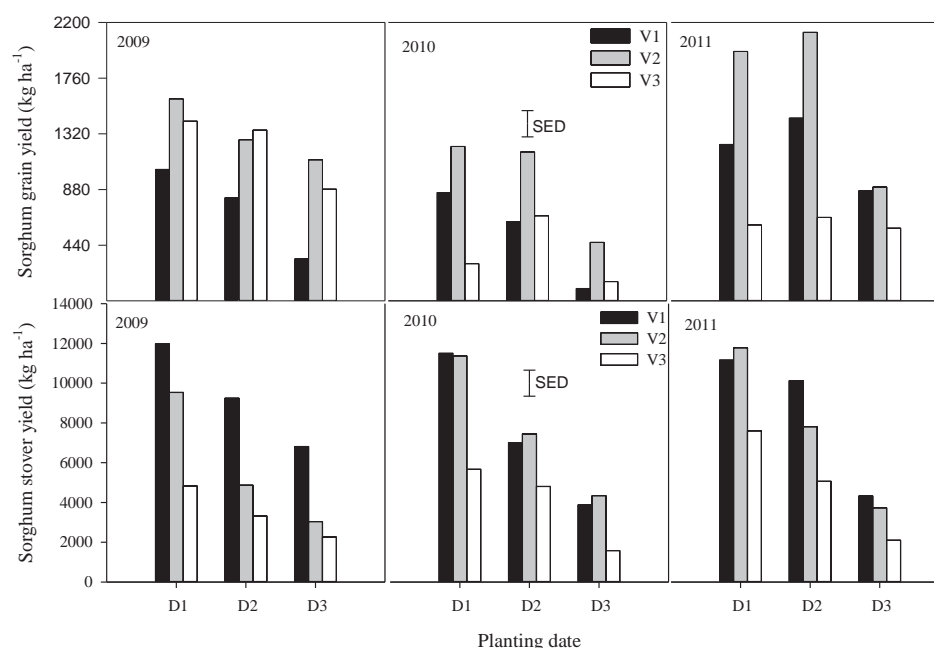


Fig 4.6: Effect of planting date on sorghum grain yield and Stover yield ( $\text{kg ha}^{-1}$ ) for three planting dates and three varieties for the three years of the experiment at N'Tarla agricultural research station, southern Mali. D1 = Early planting, D2 = medium planting, D3 = late planting, V1 = Long duration variety, V2 = medium duration variety, V3 = short duration variety. The bar represent Standard Error of Difference of mean for the interaction of year\*planting date \*variety.

## Cotton

### Seed cotton yield

The average seed cotton yields were not significantly different among years (Table 4.4). Cotton yield at D1 was 28% larger than yield at D2 and yield at D1 and D2 outperformed yield at D3 for all varieties (Table 4.4). There was no significant difference among the three varieties.

The analysis of the interaction of planting date by variety on cotton yield over the three years (Fig 4.7) indicated that a late planting date resulted in less yields independent of the year. Cotton yield at D1 was greater than at D2 which was also significantly larger than D3 for all the varieties. The effect of year by variety and planting date by variety were not significant indicating that change in year or planting date did not influence the cotton yield among varieties (Fig 4.7 and Table 4.4).

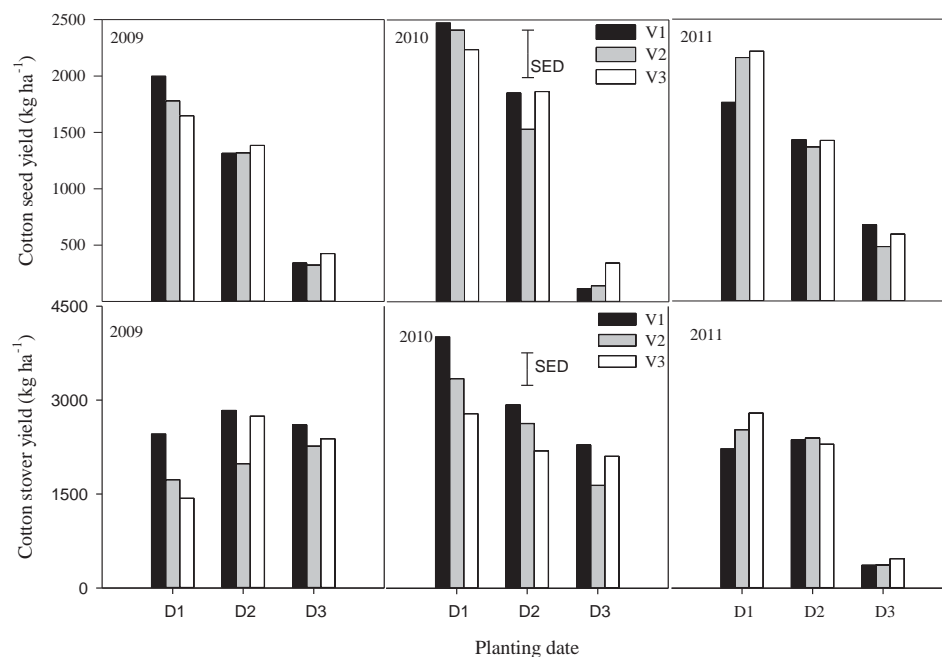


Fig 4. 7: Effect of planting date on seed cotton yield and Stover yield (kg ha<sup>-1</sup>) for three planting dates and three varieties for the three years of the experiment at N'Tarla agricultural research station, southern Mali. D1 = Early planting, D2 = medium planting, D3 = late planting, V1 = Long duration variety, V2 = medium duration variety, V3 = short duration variety. The bar represent Standard Error of Difference of mean for the interaction of year\*planting date \*variety.

#### ***Cotton stover yield, harvest index and time to flowering***

Cotton stover yield differed significantly from year to year (Table 4.4). Stover yield in 2010 was respectively 15% and 34% larger than the stover in 2009 and 2011, respectively. Stover yields at D1 and D2 were similar but significantly larger than that at D3. Differences between varieties were not significant. The interactions of variety by planting on cotton stover yield were not significant. The interaction of variety by planting date showed a significant

decreased of cotton harvest index with delay in planting (Table 4.4). The duration from planting to flowering of cotton did not change significantly with planting date (Table 4.5).

#### 4.4. Discussion

##### 4.4.1. Seasonal rainfall and crop yield

Results show that under fertilized conditions, the maize cropping system yielded best of all cereals in all three seasons, even in the relatively dry year 2011. When comparing the rainfall of three years of the experiment with long term rainfall data (for the period 1965 - 2005, Fig 4.8) only 11% of the 40 years in the database received less rainfall than 700 mm. The rainfall recorded in 2009 is very close to the long-term median annual rainfall amount and falls in the rainfall class of 800-900 mm which corresponds to rainfall received in 22% of the 45 years of recorded rainfall. This means that maize will outperform the other cereals in grain yield also in the long term, and it is therefore expected that the area grown with maize in the Sudano-Sahelian zone will continue to expand even under dry conditions.

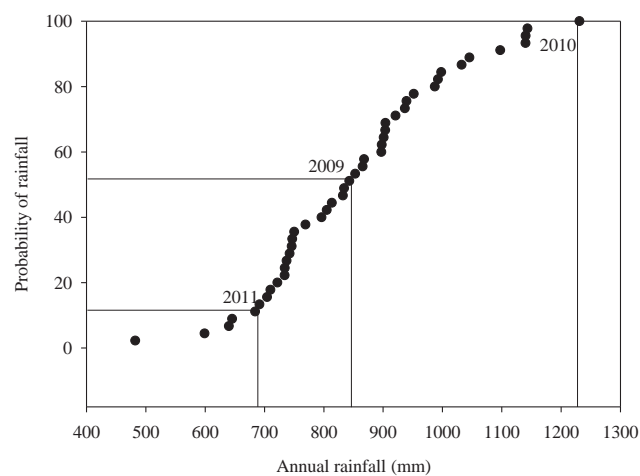


Fig 4.8: Cumulative distributions of annual rainfall over the period 1965 – 2005 for NTarla agricultural research station at NTarla, southern of Mali.

Our results are consistent with regional analyses across four west African countries showing that the average yield of maize is larger than that of millet and sorghum (Bayala et al., 2012). This helps to explain why the area under maize as well as total maize production has increased during the past two decades in southern Mali replacing sorghum and millet. Recent research has shown that the increase of the area under maize varies according to the region and its rainfall. In low rainfall areas the increase is less than in high rainfall areas (Conijn et

al., 2011; Kouressy et al., 2003). The increase in maize production area is also strongly related to cotton production (Laris and Foltz, 2011). Indeed, the Compagnie Malienne de Development des Textiles (CMDT) supplies chemical fertilizer and pesticides to farmers and also gives them the possibility to pay the costs of the inputs on credit from their cotton income. This gives them the chance to obtain inputs without having cash available. The amount of chemical fertilizer for maize provided on credit to farmers depends on their area cultivated with cotton. This cropping system, cotton in rotation with cereals, provides more harvest security for farmers by reducing the risk of complete crop failure (Francis, 1986). In this system the cereals following cotton in the rotation benefit from the application of chemical fertilizer to cotton (Bationo and Ntare, 2000; Sisworo et al., 1990). There are also indications that this rotation decreases disease pressure (Bennett et al., 2012). However, a drawback of this cotton –cereal rotation is that if prices of cotton collapse, this has direct implications for cereal production. Nubukpo and Keita (2006) and Djouara et al. (2006) showed that a substantial decrease of the cotton price results in less inputs used in cotton. The food production risk associated to this linked cotton-cereal rotation might increase in the near future. Future climate projections indicate an increased variability of rainfall, likely resulting in more dry spells, and an increase of temperature (IPCC, 2007a), factors that adversely affect cotton production (Traore et al., 2013).

The grain yields of millet and sorghum varied independently of the amount of annual and seasonal rainfall (Fig 4.2). The highest seasonal rainfall was received in 2010, while the largest yield of millet was obtained in 2009 and the largest yield of sorghum in 2011. This result is in agreement with Traore et al. (2013) who showed through an analysis of long-term (from 1965 to 2005) rainfall and crop yield data (from 1965-1994) in southern Mali that there was no significant relation between rainfall amount and sorghum yield. It can be inferred that rainfall is not the major yield-limiting factor for the traditional cereal crops like millet and sorghum in the study area. Although sorghum can tolerate short periods of water deficit, long-term and severe stress can negatively affect growth and final yield (Assefa et al., 2010)

In our study, the yield of cotton in 2010 was larger than in 2009 and 2011. The positive correlation between cotton yield and seasonal rainfall (Fig 4.2) is in agreement with the correlation found from an analysis of long term seasonal rainfall and cotton yields (Traore et al., 2013). Cotton needs 600 – 700 mm of water for its production cycle (Alberge et al., 1985; ITC, 2011) and the most important factor determining the yield is the rainfall distribution, especially during the vegetative phase (Traore et al., 2013). In general high rainfall in a season is accompanied by a better intra-season rainfall distribution (Alberge et al., 1985).

However, excessive rain might result in deterioration in fibre quality and cause flower shedding, thereby reducing cotton yield (Chaudhry and Guitchounts, 2003), explaining probably the lower yield in 2011.

The effect of inter-annual rainfall variability on grain yield varied depending on the crop and planting dates. In our study, the response of maize stover to annual rainfall variability is more pronounced (especially for early planting) than that of grain yield. In a year with much rainfall (2010) a larger stover yield was obtained but grain yield remained similar to that obtained in 2011 with less rainfall. It is reported that the difference between the stover and grain yield response might be due to an increase in translocation of photosynthates to the ripening grain in case of water stress (Tanaka and Hara, 1974). However, the maize grain yield at early planting in 2011 was less than that with medium planting, whereas in 2009 and 2010 they were similar. That might be related to the poor rainfall distribution at beginning of the rainy season in 2011 (13 days of continuous dry spell in June after emergence) indicating the sensitivity of maize to erratic rainfall conditions, especially at the juvenile stage. As a consequence, drought occurring at the seedling stage affects crop establishment, forcing farmers to replant their crops (Edmeades et al., 1993; Kamara et al., 2003).

For millet and sorghum the yield response to seasonal rainfall variability was less obvious. In a year with much rainfall (2010) a smaller grain yield of sorghum was obtained while a larger yield was obtained in the driest year (2011) indicating the ability of these crops to perform under dry conditions. However, other studies show that despite the resistance of these crops, varieties react differently (Fussell et al., 1991). Thus, Do and Winkel (1993) found that, with water stress, the decrease in yield for different millet varieties varied between 14 and 40%. In our study average yield of the three varieties of millet at D1 and D2 in 2011 was less than half the yield at D1 and D2 in 2009 and 2010. Poor millet grain yields can also be due to diseases; mildew (*S. graminicola*) can lead to yield loss of 3 to 21 % in Mali (CILSS, 1987). With regard to cotton, the relation between stover and rainfall on the one hand and cotton seed and rainfall on the other hand was more obvious (Fig 4. 2).

#### **4.4.2. Role of planting date**

Our results showed that differences in maize and sorghum grain yields between early and medium planting dates are smaller than the difference with late planting. This is in agreement with Kamara et al. (2009) who showed that earlier and medium plantings in the Sudano-Sahelian zone of Nigeria have the advantages faster growth and earlier flowering, thereby avoiding drought stress during pollination. Based on these results it can be inferred that for

grain production, there is a possibility to delay planting of maize and sorghum. Therefore, with a late or uncertain start of the rainy season, planting of sorghum and maize can be delayed from the beginning of June to early July without a major decrease in grain yield. This finding is in agreement with Conley and Wiebold (2003). Assefa et al. (2010) found that planting within a range of 30 days had a small and inconsistent effects on sorghum grain yield. Sultan et al. (2005) identified the month of June as the best planting period for sorghum to achieve high attainable yields and minimize the effects of drought.

Lower yields of maize and sorghum with late planting may be due to poor soil moisture availability during the reproductive stage and grain-filling period of the crop. The flowering period of late planted maize occurred from the end of September to mid-October, a period during which rainfall is considerably less than in the other months of the rainy season. Flowering in September means that grain-filling will extend to October, a month with little or no rainfall, which is problematic on sandy soils with a poor water retention capacity (Hoogmoed and Klaij, 1988). Other research indicated that yield components such as kernel weight and ear length are adversely affected when planting is delayed (Beiragi et al., 2011).

For millet, early planting was not a good option over the three years and for all of the three varieties. With early planting the entire vegetative growth stage coincides with excessive moisture availability, and maturation of the grain occurs in August when rainfall exceeds evapotranspiration substantially. These are ideal conditions for head mould caused by saprophytic as well as parasitic fungi, reducing the yield of millet (Chandrashekar and Satyanarayana, 2006; Kassam et al., 1976). Bacci et al. (1999) suggested that early planting also leads to a marked asynchrony between the time corresponding to maximum leaf area index and the grain filling phase, characterized by the maximum sink demand and, secondly, to a long time interval during which stem growth and panicle growth are in direct competition for dry matter accumulation during grain filling (Craufurd and Bidinger, 1989), two factors which might also reduce harvestable yield of millet.

Late planting was also not a good option for cotton over the three years and for the three varieties. Delay in planting date systematically leads to a delay of the flowering period and therefore a delay in opening and maturing of the bolls. As cotton has indeterminate growth, late planting tends to result in continuous growth without maturing before the cessation of rainfall. As a consequence, significant numbers of un-opened and immature bolls are produced (Rapidel et al., 2009). Therefore, cotton planting is strictly fixed in the sowing calendar and in a farm with labour constraints, farmers will delay planting cereals in order to plant cotton on time.

Other studies (Kamara et al., 2009; Soler et al., 2008) have shown the importance of planting date for enhancing crop productivity. Farmers plant as early as possible to take advantage of the flush of available nitrogen associated with early rains and avoid weed pressure (Stoop et al., 1981; Vaksman et al., 1996). They do this although such early planting increases the risk of failed establishment and re-sowing (Sultan et al., 2005), and requires more investment in pest and weed management. In many West African farming systems, planting date may be delayed because of the free grazing of animals at the beginning of the season, which can cause significant damage to the establishing crop and because of bird damage which is problematic when grain filling is out of phase with that of neighbouring crops (Andrews, 1973; Cochemé and Franquin, 1967).

A major challenge of adaptation strategies to climate variability and change is to match cropping duration to the length of the rainy season, so that the crop reaches physiological maturity. Another key issue is the seasonal rainfall distribution, especially at the beginning of the rainy season when planting decisions are taken. Previous findings showed that the start of the season determines the length of the cropping season, with a late start resulting in a short season (Traore et al., 2013). Our results indicate that a moderate delay does not harm performance of maize and sorghum, while early millet planting is best avoided. This offers room for accommodating the early planting requirements of cotton.

#### **4.4.3. Role of variety and interaction with planting date**

There was no significant interaction between planting date and variety for cotton and maize. Other studies found that long duration varieties produced more with early planting because they could make use of the longer period for grain filling (Agele, 2006; Bello et al., 2012; Hussain et al., 2011). Furthermore, short duration varieties require lower temperature sums to reach flowering, and are in general smaller and have fewer leaves, with a smaller associated grain yield (Akbar et al., 2008; Shi et al., 2008). In our study the lack of significant differences between maize and cotton varieties, and the absence of an interaction with planting date, may be due to the relatively small differences between the varieties in the time needed to reach flowering and maturation (Rurinda et al., 2013). Yattara and Sissoko (2007) found a similar result when they screened all cotton varieties currently grown in the cotton district of southern Mali and for a short duration variety of millet, Coulibaly (1995) also obtained high yield with late planting.

For millet and sorghum, varieties performed differently with the delay in planting date. The short duration variety of millet produced relatively high yields with late planting indicating its better adaptation. On the other hand, late planting of the long duration variety systematically resulted in poor yields. For millet and sorghum there was a significant reduction of the time to flowering for the varieties which are photoperiod sensitive when planting was delayed.

Early flowering and yield in pearl millet are sensitive to water deficits (Mahalakshmi and Bidinger, 1985; Sultan et al., 2005) and water stress during the reproductive stages can stop the development of pollen and ovules, and induce premature abortion of fertilized ovules (McWilliams, 2003; Saini, 1997). The choice of the millet variety is thus as important as planting date, and is influenced by the latter. Clear choices need to be made by the farmer depending on the start of the rainy season. When a short duration variety is planted early, the harvest time coincides with the heavy rainfall period in August resulting in increased incidence of spikelet rot and a lower grain yield. If planting is late on the other hand, this variety is the best option. Long and medium duration millet varieties have a high capacity of adjusting their flowering time, whatever the planting date.

This flexibility is also possible with sorghum. With both millet and sorghum, the main characteristic allowing for flexibility in managing climate variability is their photoperiod sensitivity. Whatever the planting date, photoperiod sensitive varieties reach the flowering stage at around the same date. This genetic characteristic is exploited in breeding to let the timing of flowering coincide with the end of the rainy season (Bazile and Soumare, 2004; Kouressy et al., 2008). It is therefore an essential characteristic for adaptation to climate variability: by changing the length of the cycle, plants improve their use of the water received during the rainy season (Craufurd et al., 1999; Craufurd and Aiming, 2001; Foliard et al., 2004) which also helps to avoid the risk of drought, especially at the end of rainy season. It gives farmers the flexibility to adjust planting dates to take advantage of early rains while still getting a modest crop when rains are delayed (Dingkuhn et al., 2008).

#### 4.4. Importance of stover yield production in the system

For maize, millet, sorghum and cotton, the largest stover yields were obtained with early planting. In general, the longer planting is delayed, the less total stover yield is produced. This result is in agreement with earlier observations. (Bacci et al., 1999; Carberry et al., 1985; Craufurd and Bidinger, 1988; Kouressy et al., 2008). The positive effect of early planting on crop stover can be attributed to an increase in the leaf area index (data not shown) and to an increase of the life span of the leaf, thereby resulting in a high total amount of light intercepted (Craufurd and Bidinger, 1988). The timing of planting therefore depends on the



farmer's production objectives. In the Sudano-Sahelian region communal grazing land has diminished over the last two decades and livestock have become more dependent on crop residues, especially during the six-month long dry season. For cattle owners, stover yield is often as important as grain yield. In this system, cattle strongly depend on crop residues, and the cropping system heavily depends on animals for land preparation and manure production (McDowell, 1988).

#### 4.5. Adaptation to climate change and to variability regional scale

Farmers in the Sudano-Sahelian region face erratic rainfall patterns which result in recurring food crises. Climate change is likely to act as an additional stress on these smallholder livelihoods (CGIAR, 2009). As such, even though farmers have experience in dealing with climate variability and uncertainty, the increase in ranges of variability creates substantial challenges for the entire range of food producers from small to large scale (Crane et al., 2011). There is a need to perform consistent assessments of climate change impacts on crop yields and of the effects of different adaptation strategies at the regional scale. However, producing reliable future agricultural production scenarios remains challenging because of large uncertainties in regional climate change projections, in the response of crops to environmental change (rainfall, temperature), in the coupling between climate models and crop productivity functions, and in the adaptation of agricultural systems to progressive climate change (Challinor et al., 2007).

A main constraint in crop production in many West African countries is the mismatch between the period needed for crop maturity and the highly variable length of the growing season. This mismatch is likely to increase based on scenarios for climate change in the region. Increases in temperature can reduce the time needed for growth and grain production of maize and millet (Muchow et al., 1990). From this perspective an increase in temperature could lead to earlier harvest which may help to avoid end of season drought. However, few studies are available that study these multiple interactions caused by climate variability and possible changes in climate. Such interactions need further investigation before impacts of climate change can be interpreted with confidence.

#### **4.5. Conclusions**

We identified possible adaptation strategies for farmers to deal with the high inter-annual variability in rainfall amount and distribution in the Sudano-Sahelian region. For fertilized cereal crops, maize performed best across the three seasons. Late planting resulted in significant yield decreases for maize, sorghum and cotton, but not for millet. For the four crops the largest stover yield are obtained with early planting. Adaptation to climate change and variability is not a straightforward choice for early or late planting, nor for long or short duration varieties. For the best choice, information on planting date and variety needs to be combined and based on the nature of the current weather. Drought risk can be avoided by better crop management decisions such on planting date (do not plant too early or too late) in combination with varieties that adapted to current rainfall.

A major challenge is timely access to the seed of crop varieties that fit well to the duration of rainy season. Choosing such a variety relies on effective rainfall prediction, information that is currently neither accessible to the Sudano-Sahelian farmers, nor available in a way that most farmers can understand and take advantage for planning their cropping system.

**Impact of future climate change on maize and millet production and adaptation options for cropping systems in the Sudano-Sahelian zone of West Africa**

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### Abstract

Future climate change will have far reaching consequences for smallholder farmers, the majority of whom depend on agriculture for their livelihoods and have a low capacity to adapt. We used a long-term time series of future climate for the Sudano-Sahelian zone of Mali coupled with the Agricultural Production Systems sIMulator (APSIM) model to analyse impacts of future climate change on cereal production. We analysed changes in future rainfall, maximum and minimum temperature under two climatic scenarios leading to a radiative forcing of  $4.5 \text{ Wm}^{-2}$  and  $8.5 \text{ Wm}^{-2}$ ; to assess the climate change impact on yield of maize and millet, and to evaluate potential adaptation options of crop management.

In southern Mali, the temperature will increase over time. Generally stronger increases occur in the rcp8.5 scenario compared to the rcp4.5 scenario. The total annual rainfall is unlikely to change. By mid-century predicted maize grain yield losses were 45% and 47% with farmer's practice in the rcp4.5 and rcp8.5 scenarios respectively. The recommended fertilizer application did not offset the climate change impact but reduced the yield losses to 38% of the baseline maize yield with farmer's practice. For millet median yield loss was 16% and 14% with farmer's practice in the rcp4.5 and rcp8.5 scenario. If the recommended fertilizer rates are applied to millet, the predicted yield losses with farmer's practice due to climate change are reversed in both climate scenarios.

Coping with climate change appears to be possible. If current crop management is improved by avoiding delays in planting, application of recommended fertilization rates and use of best performing crop varieties yield losses due to climate change can be compensated and even turned into a yield increase compared with current yields.

**Keys words:** Crop simulation modelling, planting date, fertilizer use, APSIM, sub-Saharan Africa, Mali

### 5.1. Introduction

Climate change is likely to adversely affect food production in many regions of the world, especially in developing countries where a large fraction of the population already faces chronic hunger (Lobell et al., 2008). In sub-Saharan West Africa, the observed decrease in rainfall (Dai et al., 2004; Nicholson, 2001) associated with an increase in temperature since the 1970s has led to a decline in production (Barrios et al., 2008; Traore et al., 2013). By end of the century climate projections show an increase of temperature (1.1 °C -4.8 °C ) and an increase of contrast between wet and dry season for the Sahelian region (IPCC, 2013).

Several studies evaluated the impact of current and future climate on crop production (Roudier et al., 2011; Sultan et al., 2013). Schlenker and Lobell (2010), have shown that even if rainfall remains constant by mid-century, crop yields would decrease by about 15%, probably due to the effect of high temperature reducing the length of the crop growth cycle and increasing water stress through higher evaporation losses.

Crop yield impact studies for Africa illustrate a large dispersion of yield changes ranging from -50% to +90% under various climate change scenarios (Roudier et al., 2011). Generally, the reported changes in crop yield are mostly negative (Challinor et al., 2007). In West Africa, the predicted impact is larger in Sudano-Sahelian countries, with an average yield loss of 18% compared with an average yield loss of 13% in southern Guinean countries (Sultan et al., 2013). This difference is likely due to the drier and warmer climate in the more northerly countries. In Mali, future crop yields will vary between -17% and +6% at the national level (Butt et al., 2005a). Negative impacts of climate change on crop productivity increase in severity as warming intensifies, highlighting the importance of coping with global warming.

As IPCC's Fifth Assessment Report (AR5) presents new evidence of climate change (IPCC, 2013), adapting cropping systems to the likely climate changes is essential. Various adaptation options that help Malian farmers to cope with current climate variability could be considered. In general, these are farm production practices (water management, crop landraces, fertilization) but also income/asset management (diversification of activities, migration) (Chuku and Okoye, 2009). Shifting the sowing date to the start of the season is another common practice of farmers in semi-arid regions (Muller et al., 2010). Crop simulation studies for West-Africa showed that sowing date and cultivar type adaptation can reduce the negative climate change impacts and even increase crop yields (Tingem and Rivington (2009). For example, a simulated 15% and 40% reduction in maize and sorghum

yield respectively due to climate change was converted to a 32% and 18% increase respectively with the use of different variety with a longer crop growing period (Tingem and Rivington, 2009). Moreover, Butt et al. (2005b) argued that by implementing adaptive responses such as the use of high-temperature-resistant crop varieties together with addressing soil fertility decline, economic gains could exceed losses due to climate change in Mali.

The broad scale of assessment in the few impact studies that have taken into account adaptation options by farmers (Fraser et al., 2011), makes their findings difficult to translate into knowledge that can drive local solutions. Local studies with crop models generally result in models that perform better for specific locations (soil nutrients and water conditions), compared with regional approaches (Fischer et al., 2005) and they can also help farmers to make appropriate decisions. Linking climate change scenarios to crop simulation modelling to assess the response of crop production to climate change in combination with adaptive farm management, can provide information that can enhance strategic decision-making by farmers and policy to adapt to novel challenges (Rosenzweig et al., 2013). Thus, more work on likely crop responses to climate change needs to be done at various locations to generate more information in order to reduce the uncertainty about the possible impacts of the changing climate on crop yields. In particular, these analyses are critical in African countries where research on impact and adaptation studies is still scarce compared with other regions (White et al., 2011). Hence, it is imperative to better understand future climate change and variability, the impact on crop production, and the potential of adaptation options for southern Mali.

We analysed long-term time series of future climate data for southern Mali and used the APSIM crop growth simulation model, which we calibrated and tested using data from a three years field experiment at N'Tarla agricultural research station. The objectives of this study are: (i) to analyse changes in future rainfall, maximum and minimum temperature under two climatic scenarios leading to a radiative forcing of  $4.5 \text{ W m}^{-2}$  and  $8.5 \text{ W m}^{-2}$ ; (ii) to assess the impact of climate change on yield of maize and millet, and (iii) to evaluate potential adaptation options of crop management.

## 5.2. Materials and methods

### 5.2.1 Site

We examined the effects of future climate on crop production at N'Tarla (12°35'N, 5°42'W 302 m.a.s.l.), situated at about 50 km from Koutiala in southern Mali. N'Tarla is representative for a region that occupies 14% of the Malian territory, where 40% of country population resides and where 50% of the cultivable lands are located (Deveze, 2006). The climate in southern Mali is typical of the Sudano-Sahelian zone. Average long-term annual rainfall is  $846 \pm 163$  mm at N'Tarla. The rainy season extends from May to October and the seasonal average temperature is 29 °C. During the dry season (November–April) the temperature and vapour pressure deficit increases and cropping is impossible without irrigation.

Farming systems in the region are mixed agro-sylvo-pastoral systems, focused around cotton (*Gossypium hirsutum* L.) – the main cash crop – in rotation with cereals – sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R.Br.), maize (*Zea mays* L.) – and legumes – groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* (L.) Walp.).

### 5.2.2. Experimental data

This study uses data from a three-year (2009, 2010 and 2011) experiment conducted at the N'Tarla agricultural research station, which is described in detail by Traore et al. (2014). The experimental design was a split-split-plot arrangement with three factors (crop, variety, planting date) and four replicates. The factor on the main plots was the type of crop (maize, pearl millet, sorghum, and cotton). On the sub-plots three open pollinated varieties of each crop were tested, referred to as V1 (long duration variety), V2 (medium duration variety), V3 (short duration variety) (FAO, 2008c) and three planting dates were chosen to cover the possible range of planting dates in southern Mali, referred to as D1 (early planting date), D2 (medium planting date) and D3 (late planting date). All plots received three tonnes per hectare of dry manure (organic matter content 44%) and crop-specific recommended fertilizer rates (IER/CMDT/OHVN, 1998). Plot size was 34 m<sup>2</sup> with 7 plant rows of 6 m length each.

Leaf Area Index (LAI) of maize and millet was measured at 15, 30, 45, 60 and 75 days after planting. Flowering date was recorded when the first tassel for maize and panicle for millet appeared on 50% of the plants. Crops were harvested after physiological maturity; stover and grain yields were estimated from a net plot of 12 m<sup>2</sup> (3 rows of 5 m length) in the centre of the plot to avoid border effects. Grain was separated from stover. Stover and grain sub-samples

for each treatment were bagged, weighed and oven-dried at 70 °C for 2 days to convert fresh weight to dry matter. Daily rainfall, minimum and maximum temperature and radiation were recorded at the N'Tarla meteorological station situated at about 1 km from the experimental fields. Missing values for solar radiation were replaced by values from the Koutiala weather station, at about 50 km from the N'Tarla agricultural research station.

### 5.2.3. Model analyses

The APSIM (Agricultural Production Systems sIMulator) model (Keating et al., 2003) was used to evaluate climate change impacts on maize and millet yields, and to evaluate the adaptation options of crop management (see below, section 2.5). The APSIM Maize (7.4) and the APSIM millet (7.4) modules together with the soil water module and the soil nitrogen module within APSIM were parameterized and tested using the results of the above described experiment (Traore et al., 2014). Using simulated data of climate change scenarios (Taylor et al., 2012), the effect of future climate on crop production was estimated. In this way, we simulated the growth of maize and millet as limited by soil water and nitrogen. Other growth reducing factors were accounted for by assuming a suboptimal value of the radiation use efficiency (RUE) obtained through model calibration.

### Model parameterization

The key crop and soil parameters used in APSIM are derived from literature and one year (2010) of experimental field observations (Table 5.1 and 5.2). Cultivar characteristics were based on observed phenological characteristics: crop phenology documented during the experiment was used to calculate the thermal time between crop phases from germination to maturity (Table 5.1). Base temperature, grain maximum number per head and grain growth rate were calibrated based on observed biomass and grain production data of 2010. For the regression coefficients between the area of the largest leaf and total leaf number of millet published data were used (Akponikpè et al., 2010). Soil water content at the drained upper limit (*DUL*), at the lower limit (*LL*), and at saturation (*SAT*) were based on soil measurements performed at the experiment (Table 5.2). The bare soil runoff curve number was set to 40 to account for low runoff due to the flat nature of the topography and the high infiltration potential of the sandy soil. Soil organic carbon, soil pH and soil bulk density values were measured at the experimental site.



Table 5.1: Crop parameter for the long (V1), mid (V2) and short (V3) duration varieties of maize and millet used in the APSIM simulations

|        |  | V1    | V2    | V3    | Units                 | Ref.                    |
|--------|--|-------|-------|-------|-----------------------|-------------------------|
| Maize  | Emergence-end juvenile                   | 307   | 290   | 263   | °C day                | Observed                |
|        | End juvenile- floral initiation          | 31    | 31    | 33    | °C day                | Observed                |
|        | Flag leaf-flowering                      | 15    | 15    | 18    | °C day                | Observed                |
|        | Flowering-start grain filling            | 191   | 191   | 185   | °C day                | Observed                |
|        | Flowering - maturity                     | 620   | 620   | 589   | °C day                | Observed                |
|        | Day length photoperiod to flowering      | 12.5  | 12.5  | 12.5  | H                     | Default                 |
|        | Day length photoperiod for insensitivity | 24    | 24    | 24    | H                     | Default                 |
|        | photoperiod for insensitivity            | 23    | 23    | 23    | °C/H                  | Default                 |
|        | Base temperature                         | 10    | 10    | 10    | °C                    | Estimated               |
|        | Grain maximum number per head            | 530   | 530   | 530   | number                | Estimated               |
|        | Grain growth rate                        | 8     | 8     | 9     | mg/day                | Estimated               |
|        | Radiation use efficiency                 | 1.6   | 1.6   | 1.6   | g/MJ                  | Default                 |
|        | Transpiration use efficiency             | 0.009 | 0.009 | 0.009 | kPa                   | Default                 |
| Millet | Emergence-end juvenile                   | 430   | 400   | 315   | °Cdays                | Observed                |
|        | End juvenile- floral initiation          | 112   | 112   | *     | °Cdays/h              | Default                 |
|        | Flag leaf-flowering                      | 60    | 60    | 60    | °Cdays                | Observed                |
|        | Flowering-start grain filling            | 100   | 100   | 100   | °Cdays                | Observed                |
|        | Flowering - maturity                     | 548   | 457   | 508   | °Cdays                | Observed                |
|        | Regression of largest leaf area          | -807  | -807  | -807  | mm <sup>2</sup>       | Akponikpè et al. (2010) |
|        | Regression of largest leaf area          | 1137  | 1137  | 1137  | mm <sup>2</sup> /leaf | Akponikpè et al. (2010) |
|        | Grain number per head                    | 3500  | 2000  | 3200  | grain/head            | Estimated               |
|        | Grain growth rate                        | 0.42  | 0.42  | 0.42  | mg/grain/day          | Akponikpè et al. (2010) |
|        | Radiation use efficiency                 | 1.3   | 1.3   | 1.3   | g/MJ                  | Akponikpè et al. (2010) |
|        | Transpiration use efficiency             | 0.009 | 0.009 | 0.009 | kPa                   | Default                 |

\*V3 is not photoperiod sensitive

Table 5.2: Soil parameters used in the APSIM simulations

|                                      | Acronym | 0-10  | 10-20 | 20-30 | 30-40 | 40-60 | 60-80 | units | Ref.           |
|--------------------------------------|---------|-------|-------|-------|-------|-------|-------|-------|----------------|
| Bulk Density                         | BD      | 1.57  | 1.57  | 1.72  | 1.67  | 1.74  | 1.65  | g/cc  | Measured       |
| Water lower limit*                   | LL      | 0.148 | 0.14  | 0.171 | 0.114 | 0.086 | 0.107 | mm/mm | Measured       |
| Drained Upper Limit                  | DUL     | 0.283 | 0.272 | 0.304 | 0.283 | 0.206 | 0.25  | mm/mm | Measured       |
| Saturated water content              | SAT     | 0.317 | 0.305 | 0.337 | 0.331 | 0.226 | 0.273 | mm/mm | Measured       |
| Soil water extraction                | KL      | 0.05  | 0.05  | 0.05  | 0.05  | 0.05  | 0.05  | /days | Estimated      |
| Layer drainage rate                  | SWCON   | 0.4   | 0.4   | 0.4   | 0.4   | 0.4   | 0.4   |       | Estimated      |
| Inert fraction of organic carbon     | FINERT  | 0.2   | 0.2   | 0.35  | 0.35  | 0.899 | 0.89  |       | Sissoko (2009) |
| Labile fraction of organic carbon    | FBIOM   | 0.04  | 0.02  | 0.02  | 0.01  | 0.01  | 0.01  |       | Sissoko (2009) |
| Soil albedo                          | SALB    | 0.13  |       |       |       |       |       | mm    | Sissoko (2009) |
| Stage1 soil evaporation coefficient  | U       | 8.65  |       |       |       |       |       |       | Sissoko (2009) |
| Stage 2 soil evaporation coefficient | CONA    | 0.01  |       |       |       |       |       |       | Sissoko (2009) |
| Bare soil runoff curve               | CN2     | 40    |       |       |       |       |       |       | Sissoko (2009) |
| Reduction in CN2_BARE                | CN_RED  | 28    |       |       |       |       |       |       | Sissoko (2009) |

\*Value for soil water lower limit was used for crop lower limit

### Model evaluation

The model was tested on the total aboveground biomass, grain yield and LAI measured in 2009 and 2011. Model performance was evaluated graphically and quantified by calculating the explained variance the root mean squared error (RMSE) and the model efficiency (EFF) (Willmott et al., 1985).

$$EF = \frac{\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (P_i - \bar{O})^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$$

Where  $O_i$  and  $P_i$  are the observed and simulated yield and  $\bar{O}$  is the mean of the observed values.

#### **5.2.4. Future climate data**

We used the latest CMIP5 (Coupled Model Intercomparison Project Phase 5) climate modelling results for historical (1976-2005) and future climate data. In order to span some of the uncertainty in climate projections, average results of five GCMs (CNRM-CM5, ECEARTH, HADGEM2-ES, IPSL-CM5A-LR, MPI-ESM-LR) were generated. This increases the accuracy of the projected output compared to the individual model simulation (Pope et al., 2007). These particular GCMs were selected firstly because they were used in the latest IPCC report (IPCC, 2013) and secondly because daily bias-corrected data for maximum and minimum temperature and rainfall were readily available on a 0.5 x 0.5 degree grid for the location of interest over the period 1976 to 2005 for the past climate and for 2006 to 2099 for the future climate. Radiation data was bias corrected according to the method of Haddeland et al. (2012). The method of Piani et al. (2010) was used to bias correct temperature and rainfall. For both methods the WATCH forcing data was used as a baseline (Weedon et al., 2011).

Results of two greenhouse gas emission scenarios described in the Special Report on Emissions Scenario (Nakicenovic et al., 2000) were used. These emission scenarios represent different likely trends in population change, economic output, land use, energy and technology (Sheffield and Wood, 2007).

In the worst case scenario (rcp8.5), as a result of continuously increasing global population and limited technological change, CO<sub>2</sub> emissions in the period 2000–2099 will multiply 4–5 times and the atmospheric CO<sub>2</sub> concentrations will rise to 850 ppm. Temperature will increase 2.0–5.4 °C. In the rcp4.5 scenario environmental protection is emphasized and world population increases at a relatively low speed. The atmospheric CO<sub>2</sub> concentrations will stabilize at 550 ppm by the end of the century. Temperature will increase by 1.1–2.9 °C.

Future minimum, maximum temperature and rainfall were compared to the base line conditions by means of graphical analyses showing monthly averages and ranges of the selected climate indicators.

#### **5.2.5. Crop production and possible adaptation options**

We first analyse the effects of climate change on crop production for the long (V1) and the short duration (V3) varieties of maize and millet at the early planting date (D1) and with current farmers' practice (F1) rates of N fertilizer (60 kg N ha<sup>-1</sup> for maize and no N for millet, respectively). Then, the effects of different cropping practices in current and future climate are explored by investigating effects of recommended fertilizer rates (85 kg N ha<sup>-1</sup> for maize

and 40 kg N ha<sup>-1</sup> for millet), three planting dates and two varieties. Both single factor and interaction effects were quantified using analysis of variance (ANOVA) procedures ( $P \leq 0.05$ ) for a general treatment design with no blocking (GenStat Edition 14 Library Release PL18.2, VSN International Ltd).

### 5.3. Results

#### 5.3.1. Model performance

Model performance for maize was good. Simulated grain yields were relatively close to observed values over the whole range of observations with explained variances of 0.89 for 2010 and 0.70 for 2009 and 2011 (Fig 5.1). For total aboveground biomass the explained variance was lower: 0.55 both for the year used for calibration and for the two years used for testing the model.

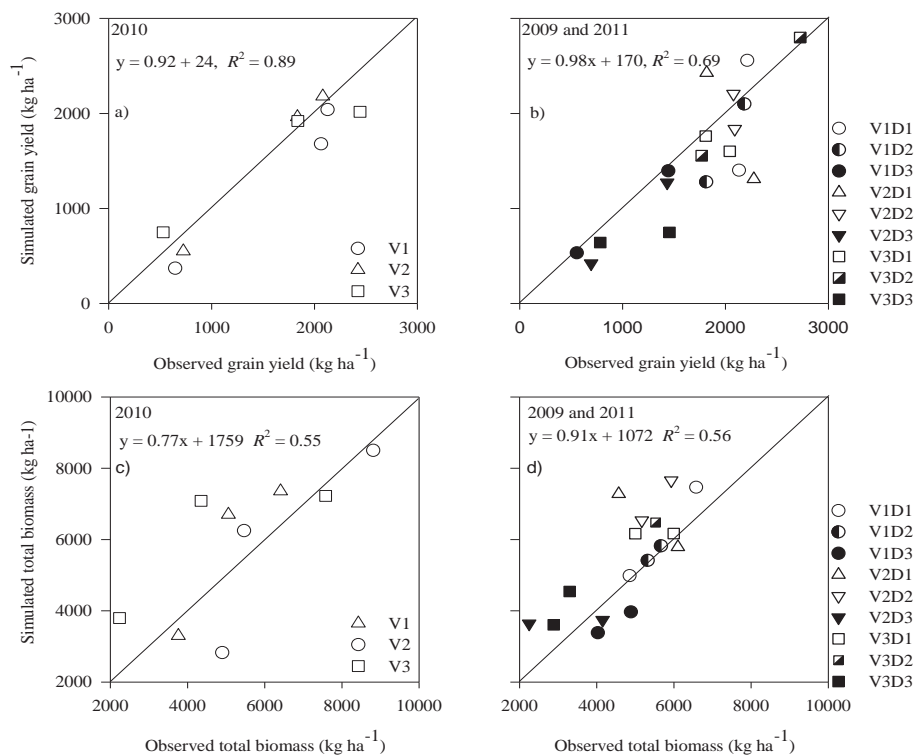


Fig 5.1: Comparison of observed and simulated grain yield of maize in 2010 for calibration (a) and 2009 and 2011 for the model test (b). (c) and (d) represent respectively comparison of observed and simulated total aboveground biomass of maize in 2010 for calibration and 2009 and 2011 for the model test. The 1:1 line is indicated in each graph.

Model efficiency for yield and total aboveground biomass was satisfactory for the three varieties (Table 5.3). Also LAI was adequately simulated with RMSE values of 0.36, 0.30 and 0.34 for V1, V2 and V3 respectively and the model efficiency was higher than 0.95 for the three varieties. Model performance for millet was satisfactory with  $R^2$  values of 0.60 and 0.45 respectively in the calibration year and the two test years (Fig 5.2). For total aboveground biomass  $R^2$  values were 0.53 and 0.71 for calibration and test datasets of the model. The model adequately simulated millet total aboveground biomass, grain yield and LAI for the three varieties (Table 5.3).

Table 5.3: Model performance statistics for maize and millet grain yield ( $\text{kg ha}^{-1}$ ), total above ground biomass ( $\text{kg ha}^{-1}$ ) and leaf area index (LAI)

|        |                           | V1   |      | V2   |      | V3   |      |
|--------|---------------------------|------|------|------|------|------|------|
|        |                           | RMSE | EF   | RMSE | EF   | RMSE | EF   |
| Maize  | grain yield               | 397  | 0.54 | 497  | 0.15 | 463  | 0.38 |
|        | Total aboveground biomass | 1333 | 0.65 | 1549 | 0.30 | 933  | 0.42 |
|        | LAI                       | 0.36 | 0.95 | 0.30 | 0.98 | 0.34 | 0.95 |
| Millet | grain yield               | 249  | 0.39 | 380  | 0.32 | 295  | 0.54 |
|        | Total aboveground biomass | 1226 | 0.77 | 1316 | 0.64 | 2040 | 0.31 |
|        | LAI                       | 0.68 | 0.79 | 0.75 | 0.74 | 0.43 | 0.85 |

RMSE: Root mean square error, EF: efficiency of the model

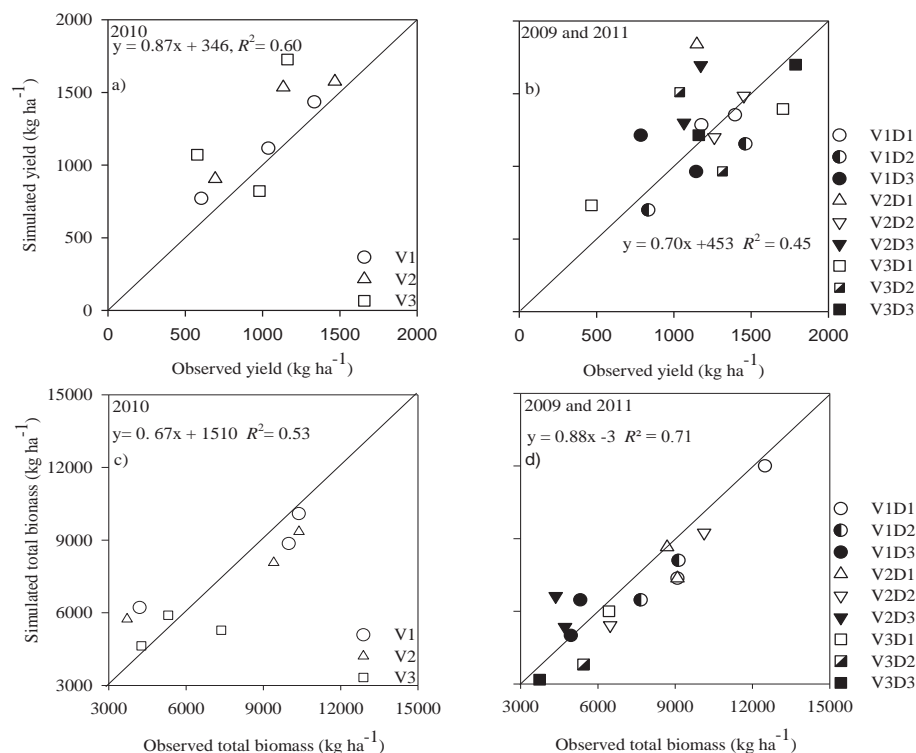


Fig 5.2: Comparison of observed and simulated yield of millet in 2010 for calibration (a) and 2009 and 2011 for the model test (b). (c) and (d) represent the comparison of observed and simulated total biomass of millet in 2010 for calibration and 2009 and 2011 for the model test. The 1:1 line is indicated in each graph.

### 5.3.2. Climate change in Mali

Climate predictions showed increasing temperature with time and generally stronger increases in the rcp8.5 scenario compared with the rcp4.5 scenario. Changes in rainfall were not significant in both scenarios throughout the 21<sup>st</sup> century. In what follows, results are shown mostly for the mid-century period (2040-2069), because for this period, meaningful changes were detected and believed to be more reliable than for the end of the century period (2070-2099).

In the simulated base line climate of the past 30 years, average maximum and minimum temperatures were 35°C and 22°C respectively. In the rcp 8.5 scenario average annual maximum and minimum temperature increased by 2°C and 2.3°C by the mid-century (2040-2069) as compared to the base line. The strongest warming will occur in April and May with an increase of 2.7°C and 3.2°C in maximum and minimum temperature respectively (Fig 5.3).

The increase in August and September (the period of flowering and maturity of many crops) is 1.5°C and 1.7°C for maximum and minimum temperature respectively.

Compared to the rcp8.5 scenario, the expected warming by mid-century is less pronounced in the rcp4.5 scenario (Fig 5. 3). In April-May maximum and minimum temperature increases by 2°C and 2.3°C respectively, while in August-September this is 1°C and 1.2°C (Fig 5.3). The average annual rainfall for the base line climate was 920 mm. By mid-century, no significant change in this amount is predicted in both the rcp4.5 and rcp8.5 scenarios (Fig 5.4).

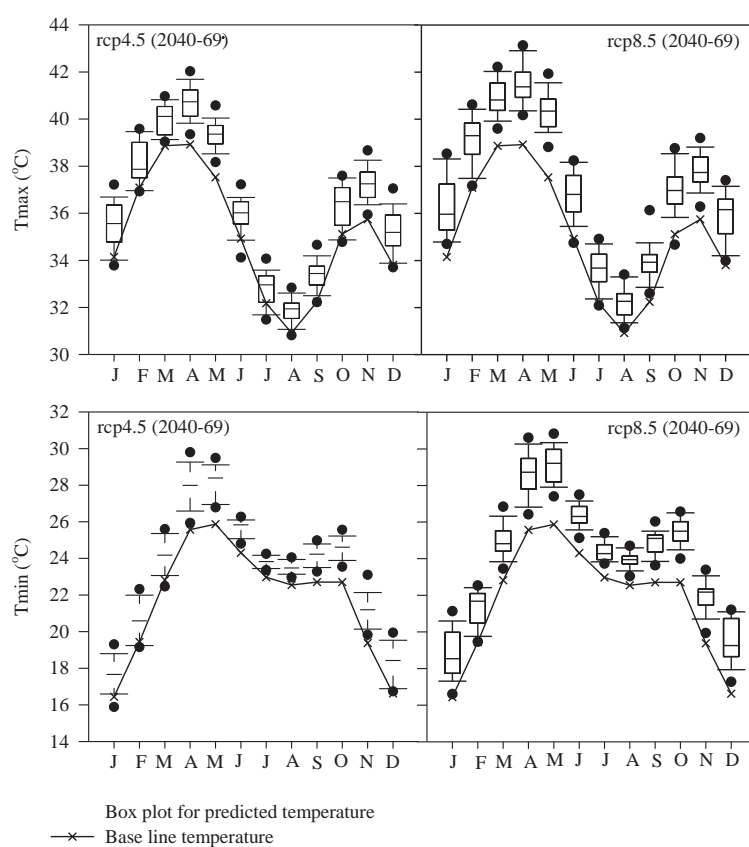


Fig 5.3: Maximum and minimum temperature during the period 2040-2069 under climate scenarios rcp4.5 and rcp8.5 compared to the simulated baseline observations (1976-2005) shown as a solid line.

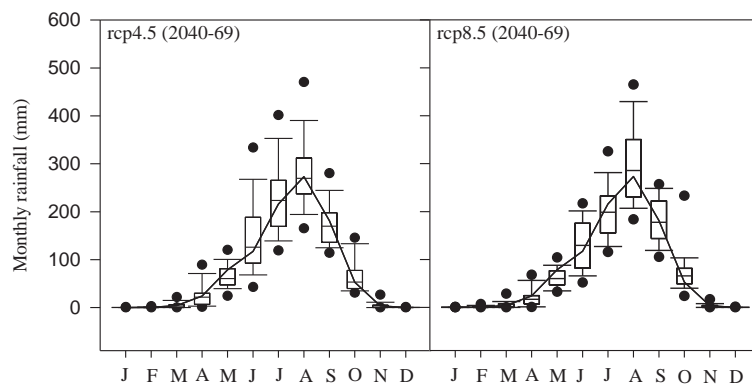


Fig 5.4: Boxplots of predicted monthly rainfall for the mid-century for two future climate scenarios (rcp4.5 and 8.5) along with predicted baseline rainfall (solid line).

### 5.3.3. Yield predictions under climate change with current fertilizer practices

For the long duration variety (V1) of maize at early planting date (D1), the median predicted grain yield in the base line climate was 2322 kg ha<sup>-1</sup> (Fig 5.5). In the mid-century period (2040-69), the median predicted grain yield declined by 37% and 42% for the rcp4.5 and rcp8.5 scenarios respectively. A similar impact of climate change was predicted for the short duration variety (V3), showing a decrease of 28% and 35% relative to the predicted baseline yield of 1796 kg ha<sup>-1</sup> for the rcp4.5 and 8.5 scenarios respectively (Fig 5.5). Comparing the two maize varieties at early planting, the median grain yield of the long duration variety was larger than the short duration variety in the baseline climate and the future climate.



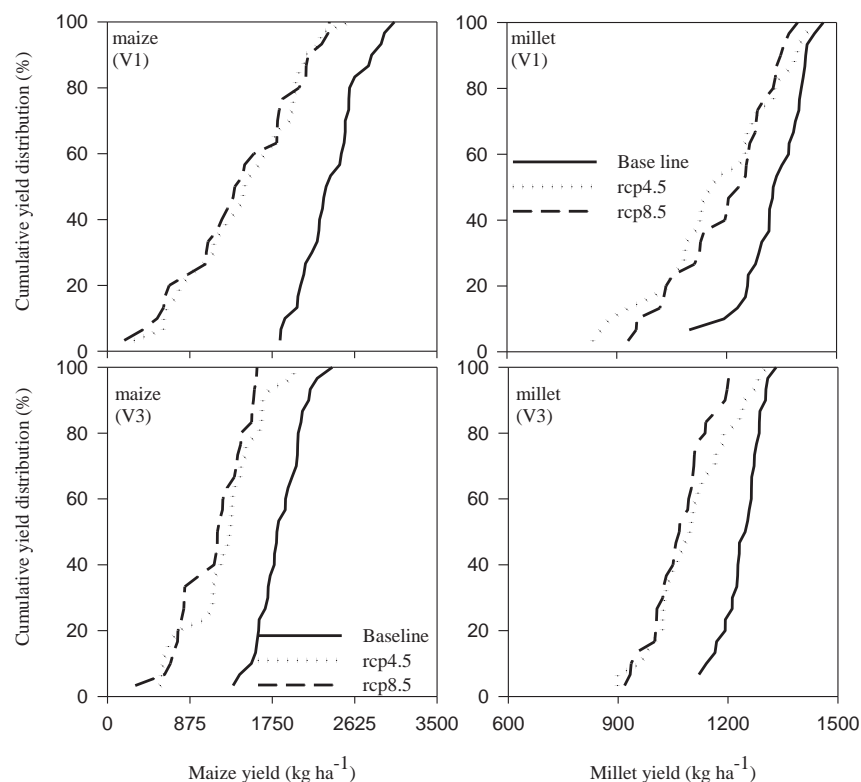


Fig 5.5: Cumulative distribution of simulated yield of long (V1) and short (V3) duration variety at early planting (D1) for maize and millet under the baseline climate and two future climate scenarios (rcp4.5 and 8.5) from 2040 to 2069.

The median predicted grain yield in the baseline condition was 1325 kg ha<sup>-1</sup> for the long duration variety (V1) of millet at early planting (D1) (Fig 5.5). Predicted median yield loss was 13% and 7% for rcp4.5 and rcp8.5 respectively (Fig 5.5). For the short duration variety (V3) of millet at early planting (D1), median predicted grain yield in the baseline condition was 1246 kg ha<sup>-1</sup> (Fig 5.5). Under the future climate, median predicted yield loss was 13% for both climate scenarios. Comparing both millet varieties at early planting revealed that the median predicted yield of the long duration variety was larger than that of the short duration variety under the baseline conditions. This difference will remain similar by the mid-century period for both climate change scenarios.

Using a grain yield threshold of 1200 kg ha<sup>-1</sup>, both maize varieties yielded more in all years of the baseline climate, whereas for millet the long and short duration variety yielded less in 10 and 20% of the years. For the long duration variety of millet yields below 1200 kg ha<sup>-1</sup> occurred in 53% and 40% of the years for rcp4.5 and rcp8.5 respectively while for maize

these values were 33% and 37%. With regard to the short duration variety of millet, yields below 1200 kg ha<sup>-1</sup> occurred in 80% and 93% of the years for rcp4.5 and rcp8.5 respectively, versus 37% and 53% of the years for maize.

### 5.3.4 Predicted time to flowering under climate change

Linear regression analysis indicated a significant ( $P < 0.001$ ) shortening of the predicted time to flowering from 2010 to 2069 for both varieties of maize and millet (Fig 5.6). For the long duration variety of maize, the simulated time to flowering was shortened by 2.5 days and 4 days for rcp4.5 and rcp8.5 respectively, while for the short duration variety the shortening was 2 and 3 days over the period 2010-2069. With regards to millet the simulated time to flowering was shortened by 2 days for both the long and short duration variety under scenario rcp4.5. For rcp8.5, the shortening was 4 and 3 days for the long and short duration variety respectively over the period 2010-2069.

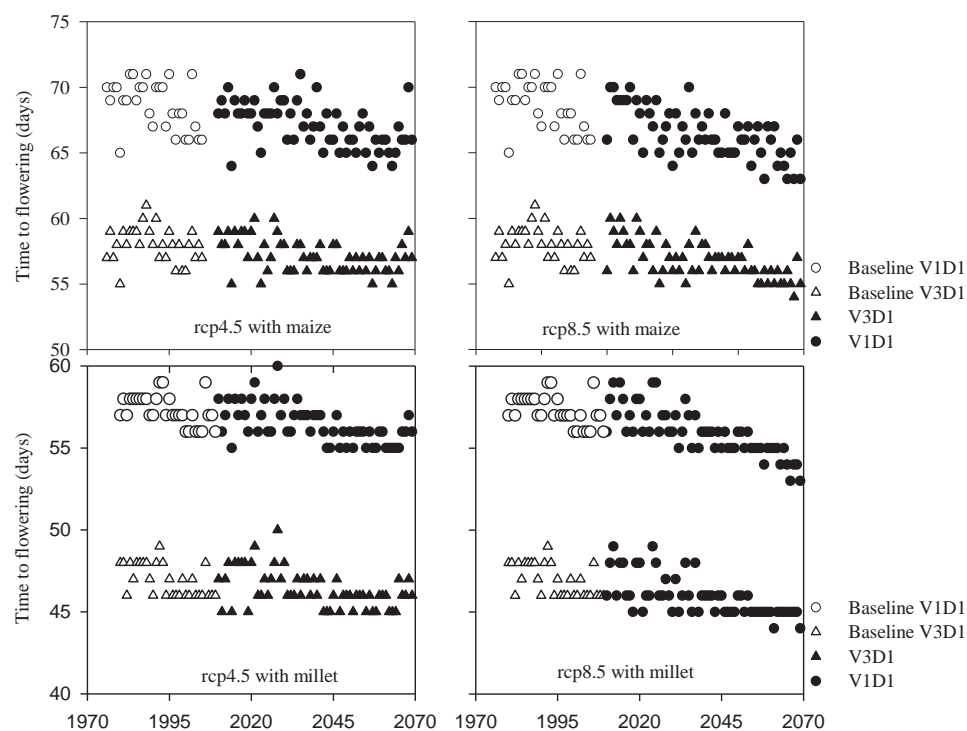


Fig 5.6: Simulated time to flowering (days) for V1 (long duration) and V3 (short duration) of maize and millet during the period 2010-2069 compared to the base line period (1976-2009) for two future climate scenarios (rcp4.5 and 8.5)

### 5.3.5 Evaluating adaptation options to future climate change

For both crops, the main effects of fertilizer, planting date, variety and climate were significant and as expected, higher fertilizer, earlier planting and long duration varieties increase the grain yields (Table 5.4). Future climate change is predicted to negatively affect grain yields across the other factor levels. In order to evaluate adaptation to climate change, we focus on the interaction effects between the crop management factors and the climate factor (Table 5.5) for both crops separately.

Table 5.4: Main effect of fertilizer, planting date, variety and climate on simulated yield of maize and millet

|                  |          | Millet                          |          |     | Maize                           |          |     |
|------------------|----------|---------------------------------|----------|-----|---------------------------------|----------|-----|
|                  |          | Yield<br>(kg ha <sup>-1</sup> ) | <i>P</i> | SED | Yield<br>(kg ha <sup>-1</sup> ) | <i>P</i> | SED |
| Fertilizer       | F1       | 951                             | 0.001    | 8   | 1170                            | 0.001    | 26  |
|                  | F2       | 1127                            |          |     | 1400                            |          |     |
| Planting<br>date | D1       | 1335                            | 0.001    | 10  | 1822                            | 0.001    | 31  |
|                  | D2       | 964                             |          |     | 1511                            |          |     |
|                  | D3       | 816                             |          |     | 522                             |          |     |
| Variety          | V1       | 1122                            | 0.001    | 8   | 1378                            | 0.001    | 25  |
|                  | V3       | 955                             |          |     | 1191                            |          |     |
| Climate          | Baseline | 1140                            | 0.001    | 10  | 1898                            | 0.001    | 31  |
|                  | rcp4.5   | 999                             |          |     | 980                             |          |     |
|                  | rcp8.5   | 977                             |          |     | 976                             |          |     |

For millet F1= application of 0 kg N ha<sup>-1</sup> corresponding to farmer practice, F2= application of 40 kg N ha<sup>-1</sup> corresponding to the recommended practice. For maize F1= application of 60 kg N ha<sup>-1</sup> corresponding to farmer practice, F2= application of 85 kg N ha<sup>-1</sup> corresponding to the recommended practice, D1, D2 and D3 correspond respectively to early (June), medium (July) and late (August) planting. V1 and V3 correspond to long and short duration.

#### Maize

There was a significant interaction effect of climate on the fertilizer - maize grain yield relationship (Table 5.5). Predicted grain yield losses were 45% and 47% with farmer's practice in the rcp4.5 and rcp8.5 scenarios respectively. Although the recommended fertilizer application did not offset the climate change impact, it reduced the yield losses to 38% of the baseline yield with farmer's practice.

The impact of climate change was similar at early and medium planting, with average yield loss of about 43% for both rcp scenarios respectively. At late planting, which results in very small grain yields, the relative yield losses were larger than 50% in both climate scenarios (Table 5.5).

Across the three planting dates and two fertilizer rates, the interaction effect between variety and climate was not significant for maize, indicating that climate change would affect the yield of the two varieties similarly (Table 5.5).

Table 5.5: Average simulated yield and interaction effect of fertilizer application, planting date and variety by climate, comprising the current and the projected mid-century (2040-2069) climate under the rcp4.5 and rcp8.5 scenarios.

|               |                           | Millet       |        |        | Maize        |        |        |
|---------------|---------------------------|--------------|--------|--------|--------------|--------|--------|
|               | Factor                    | Baseline     | rcp4.5 | rcp8.5 | Baseline     | rcp4.5 | rcp8.5 |
| Fertilizer    | F1 (farmer practice)      | 1035         | 915    | 902    | 1686         | 921    | 902    |
|               | F2 (recommended practice) | 1245         | 1083   | 1051   | 2110         | 1040   | 1049   |
|               | <i>P</i>                  | <i>0.001</i> |        |        | <i>0.001</i> |        |        |
|               | SED                       | 14           |        |        | 44           |        |        |
| Planting date | D1 (Early)                | 1443         | 1289   | 1275   | 2599         | 1476   | 1390   |
|               | D2 (Medium)               | 1059         | 928    | 905    | 2132         | 1206   | 1194   |
|               | D3 (Late)                 | 920          | 780    | 749    | 964          | 259    | 343    |
|               | <i>P</i>                  | <i>0.874</i> |        |        | <i>0.001</i> |        |        |
|               | SED                       | 18           |        |        | 54           |        |        |
| Variety       | V1 (Long duration)        | 1218         | 1082   | 1066   | 2116         | 1003   | 1017   |
|               | V3 (Short duration)       | 1062         | 916    | 887    | 1680         | 958    | 935    |
|               | <i>P</i>                  | <i>0.052</i> |        |        | <i>0.001</i> |        |        |
|               | SED                       | 14           |        |        | 44           |        |        |

Whereas recommended fertilizer rate application improved yields for both current and future climate, the effect is negligible if planting is late (D3) (Fig 5.7). Also, the fertilizer effect was stronger for the long duration variety (V1) as compared with the short duration variety both for the baseline and the future climate scenarios. If planting is delayed strongly (D3), the short duration variety appeared as a good alternative, whereas with a slight delay (D2), the long duration variety still yielded more.

### **Millet**

Simulated grain yield obtained with recommended fertilizer practice was larger than with farmer practice by about 17% under baseline climate, by 16% under the rcp4.5 scenario and by 14% under the rcp8.5 scenario (Table 5.5). If the recommended fertilizer rates are applied, the predicted yield losses with farmer's practice due to climate change are reversed in both climate scenarios (Table 5.5). The impact of climate change was similar at early and medium planting, with average yield loss of about 12% in both scenarios respectively. Delaying planting from D1 to D3 caused a strong yield loss across the baseline and future climates. With both millet varieties, a similar significant effect of climate on grain yield was obtained, with simulated yield losses for the long duration variety of 11% and 13%, and for the short duration variety of 14% and 16% under the rcp4.5 and rcp8.5 scenarios respectively (Table 5.5).

Applying recommended fertilizer rates to the long duration variety results in a strong yield increase especially at early planting in the current climate (Fig 5.7). In both rcp4.5 and rcp8.5 scenarios, fertilizer can largely offset the negative effect of climate change. For the short duration variety on the other hand, applying recommended fertilizer rates may offset the climate change effect at early planting for both rcp scenarios.

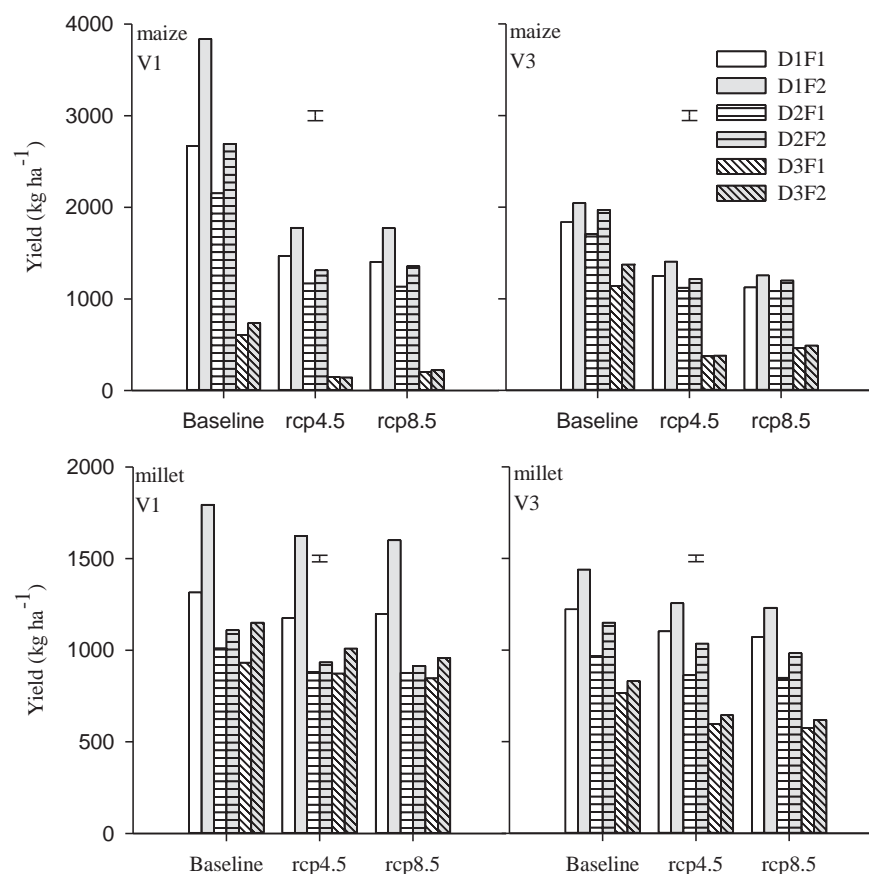


Fig 5.7: Simulated yield of long (V1) and short (V3) duration of maize and millet under the base line climate and under the two future climate scenarios (rcp4.5 and 8.5) for the mid-century (2040-2069) for southern Mali. For millet F1= application of 0 kg N ha<sup>-1</sup> corresponding to farmer practice, F2= application of 40 kg N ha<sup>-1</sup> corresponding to the recommended practice. For maize F1= application of 60 kg N ha<sup>-1</sup> corresponding to farmer practice, F2= application of 85 kg N ha<sup>-1</sup> corresponding to the recommended practice, D1, D2 and D3 correspond respectively to early (June), medium (July) and late (August) planting.

## **5.4. Discussion**

Our results showed that with both rcp scenarios, temperatures will increase in southern Mali, with negative consequences for crop productivity. If current sub-optimal crop management is improved, i.e. if delays in planting date are avoided, if recommended fertilization rates are used and if best performing crop varieties are chosen, the loss in crop yield due to climate change can be compensated and even turned into a yield increase compared with current yields. However, to achieve this crop management improvement will be a major challenge. We now discuss our main findings in more detail.

### **5.4.1. Climate change for the region**

Our results showed that the current trend of climate warming in southern Mali (Traore et al., 2013) will continue and even increase in speed, resulting in a maximum and minimum temperature increase of 2 and 2.3°C respectively by the mid-century period. Across the West African Sahel a trend of increasing maximum and minimum daily air temperatures was observed for all the three main ecological zones (Sudanian, Sahelian and Sahelo -Saharan), with minimum temperatures increasing at a faster rate (CEDEAO-ClubSahel/OCDE/CILSS, 2008). This geographically widespread warming trend in West Africa includes a tendency of drier regions warming up more than relatively wetter regions (Dai et al., 2004). As a consequence, temperature thresholds with negative effects on food production that used to be reached relatively rarely, are being reached more frequently (Stott et al., 2004) and this trend will intensify by mid - century if greenhouse gas emissions continue unabated (Stott et al., 2011).

Our results showed no clear changes in the distribution as well as in the monthly amount of future rainfall. Projections for the non-Saharan zones in Mali are highly uncertain, as individual models generate large, but disparate, responses in the Sahel (IPCC, 2007a). Although reduction of rainfall on average is not expected to be strong, a study for the Sahelian region indicates that extremely dry and wet years will likely become more frequent during the 21st century (Brooks, 2004; Dai et al., 2004).

Increasing temperatures will lead to increased evaporation and thus drying, thereby increasing the intensity and duration of droughts (Trenberth, 2011). On the other hand, increased atmospheric water vapour capacity due to warming may lead to increased water vapour in the atmosphere. This could mean that storms, and thunderstorms, being supplied with more moisture, will produce more intense precipitation events (Dai, 2001; Shinoda et al.,

1999). These two possible increases in rainfall variability, more droughts and more intense precipitation events were not captured by the average GCM data used in this study, and therefore the main changes in crop productivity due to climate change were driven by changes in temperature.

Elevated CO<sub>2</sub> concentration improve nitrogen use efficiency and crop transpiration but showed that for maize still no unequivocal evidence exist of positive effects of CO<sub>2</sub> increases on maize production (Leakey et al., 2009). Experiments have shown that for maize increased CO<sub>2</sub> reduces transpiration under well watered conditions, and increases soil water availability, but whether under water stress conditions this effect leads to increased maize yields is still unclear.

#### **5.4.2. Effect of climate change on yield of maize and millet**

Both long and short duration maize and millet varieties are negatively affected by climate change. The substantial yield reductions for both crops suggest that the temperature increase will strongly affect food production in the Sudano - Sahelian zone. Several studies have shown the potential impact of future climate change on the performance of sub-Saharan Africa agriculture (Barrios et al., 2008; Lobell and Field, 2007; Nelson, 2009; Sultan et al., 2013), but often not in great detail with a specifically calibrated and tested crop growth model. The magnitude of the reported crop yield response to climate change in sub-Saharan Africa varies considerably (-98% to +16%) (Fischer et al., 2001; Jones and Thornton, 2003; Parry et al., 2004) although the change is negative in most cases (Challinor et al., 2007). This high range of yield variability may be explained by spatial variability and the use different crop growth simulation methods. The predicted impact is larger in northern West Africa (Sudano-Sahelian countries) than in southern West Africa (Guinean countries) which is likely due to drier and warmer climate predictions for the northern part of West Africa (Challinor et al., 2007).

The negative impacts of warming on yields of maize and millet clearly highlights the importance of coping with global warming especially for those smallholder farmers with low adaptive capacity like most farmers in Mali and across the majority of Sub-Saharan African countries. Adding to that, low soil fertility of the Sahel region or inappropriate management practices of farmers could result in additional influences that are difficult to separate from that caused by climate change.



With no clear predicted change in rainfall, the observed climate impact is assigned to the increased temperature. This interpretation is in agreement with Schlenker and Lobell (2010), who found that the marginal impact of one standard deviation change in precipitation is smaller than that of one standard deviation change in temperature. Although the temperature effect is expected to be large, rainfall change can have an impact, even if it is smaller than that caused by the change in temperature. For a millet variety in Niger, a potential rainfall change strongly affected the negative temperature increase effects (+1.5°C), with a 59% and 26% crop yield loss for decreasing and increasing rainfall respectively (Salack and Traore, 2006). Roudier et al. (2011) indicated rainfall changes, still uncertain in climate projections, have the potential to aggravate or moderate impact due to temperature depending on whether rainfall decreases or increases.

Our results showed that a key cause of decreased crop yields is the reduction of the time to flowering, thereby reducing the effective period in which biomass and assimilate build up to be used for grain filling can take place. Increasing temperature results in accelerating crop respiration and limiting photosynthesis thus leading to a reduction of biomass (Waha et al., 2013b) and acceleration in maturation rates is mainly related to moisture stress (Singh et al., 1998). In our study droughts and intense rainfall events were not captured by the average of five GCMs suggesting that daily rainfall amounts are “smeared out” over the days leading to small, but very regular rainfall events, which may result in an underestimation of water stress. Increase of temperature may also lead to accelerated soil carbon decomposition (Conen et al., 2006; Knorr et al., 2005) but studies showed that this decomposition could be insensitive due to biological adaptation (Luo et al., 2001) or to the influence of other factors such as nutrient availability (Kirschbaum, 2000). Furthermore, temperature changes may also affect the length of the growing period, increase potential evapotranspiration, and may push plants closer to damaging thresholds (Easterling, 2007; Solomon, 2007). The ability of a crop to withstand heat stress depends upon the developmental stage when a heat wave occurs.

In terms of the risk of low crop yields, our results showed that, although both millet and maize productivity were impacted by climate change, the percentage of low yield obtained with millet was higher than that obtained with maize and this holds for both long and short duration varieties. This means that in terms of coping with future climate change, maize is likely to remain attractive to farmers.

However, the area of maize in the crop rotation in Mali remains less than that of millet and sorghum (Djouara et al., 2006). Given the farmers’ interest in growing maize, increase of maize areas in the cropping system at the expense of millet and sorghum could be an option

for coping with the negative impact of climate and improve farmers' incomes. However this increase must be accompanied by easy access of the farmers to mineral fertilizer.

#### **5.4.3. Adaptation options to future climate change**

We found that maize and millet yields obtained with the recommended fertilizer applications were larger than the yields obtained with farmer's practice highlighting the role of chemical fertilizer in coping with negative effects of future increase of temperature in the Sudano-Sahel zone of Mali.

Yield improvement through fertilizer application can only be achieved realistically, if the risk of investment for resource of poor farmers is reduced through increased fertilizer use efficiency (Bationo et al., 1998; Buerkert and Lamers, 1999; de Ridder et al., 2004). Given the risks involved with an unpredictable climate, farmers are not willing to invest in fertilizers but economising and improving the fertilizer management may encourage them to use more on cereal crops. Several studies have shown that the practice of micro-dosing or hill application can improve yields and farmers' income considerably (Abdoulaye and Sanders, 2005; Sawadogo-Kaboré et al., 2009; Tabo et al., 2007).

For maize and millet the effect of climate change was important for each planting date. This means whatever the planting date, climate change will act similarly, thus it is obvious that yield obtained with early planting is the best option to cope with climate impact. Farmers take the risk of planting earlier as a strategy to increase crop yields through improved nutrient availability associated with the first rains (Weber et al., 1995). In the study site, planting date varies according to crops and also according to farm types (Traore, 2007). For instance, due to its rustic characteristics, millet can be planted in dry conditions whilst such a risk is never taken with maize. Early planting is restricted by labour availability and lack of equipment (Jagtap and Abamu, 2003). Thus farms with few resources delay planting of maize or cotton resulting in low yield (Traore et al., 2014)

Despite the benefits, early planting increases the risk of failed establishment and replanting (Sultan et al., 2005), and requires more investment in pest and weed management. This constraint will still remain or will become worse, adding to the negative impacts of future climate. Changing to more early planting depends on the improvement of current planting techniques which are based on the use of a rudimentary drill that has not evolved since its introduction in 1960 (FAO, 2008a). By improving the planter in order to plant a larger area, labour efficiency could be improved therefore giving an opportunity, especially for farmers

with smaller land areas, to take advantage of the first rains at the beginning of the rainy season.

Although yields of long and short duration varieties were decreased by climate change we found that yields of a long duration variety were larger than that of short duration variety. This means that coping with future climate depends on keeping long duration varieties in the cropping system. By contrast, research efforts in the West African Sahelian zone are devoted to creating short duration varieties (Vadez et al., 2012; Vaksman et al., 2008) in order to cope with the high climate variability, especially high inter-annual rainfall variability. We argue though that the challenge is rather to find an integrated combination of both long and short duration varieties in the smallholder cropping system. This needs a clear definition of planting dates for each type of variety in relation to the pattern of the start of rainfall and to the farmers' capacity to plant crops early.

Across the region the distribution of varieties must be drawn up based on the occurrence of the length of growing period which varies with the latitude (Traore et al., 2007). The ideal option would be to identify a series of varieties that fit to each agro-ecological zone.

## **5. Conclusion**

Our study demonstrates that with both climate scenarios, that is the worst case scenario (rcp8.5) and a scenario taking into account environmental protection (rcp4.5), temperatures in southern Mali will continue to increase, with subsequent negative consequences for crop productivity. If current sub-optimal crop management is improved – if delays in planting date are avoided, if recommended fertilization rates are used and if best performing crop varieties are chosen – the loss in crop yield due to climate change can be compensated and even turned into a yield increase compared with current yields.



**General discussion**

## **6. General discussion**

### **6.1. Introduction**

Smallholder agriculture is the core contributor to agricultural production in most Sub-Saharan African countries and the main driver for family food self-sufficiency. But in most cases productivity remains desperately poor especially in the Sudano - Sahelian region where the soil fertility is inherently low, and the use of agricultural inputs is limited. As crop production is mostly rainfed, it is highly susceptible to the large inter-annual climate variability and the frequent droughts occurring during the growing season, which are typical for the region. Climate change, in the form of an increase in minimum and maximum temperature (Conway, 2009), which is likely to accelerate in the future (IPCC, 2013), adds a further challenge to agriculture.

Research on climate change and variability and their impacts on agriculture play a key role in the development of both tactical and strategic means to minimise the impacts. Attempts to address the problem of poor agricultural productivity of smallholder farms with low adaptive capacity to current and future climate, need to combine local knowledge of the functioning of the farming systems of interest, quantification of possible effects of adaptation options through experimentation and modelling and participatory evaluation of these options. Thus, in this thesis I combined understanding of past and future climate on the one hand and the current cropping practice in the region of interest on the other hand in order to identify cropping strategies that may allow farmers adapting to climate variability and change.

The general purpose of this thesis was to quantify the possible change of past and future climate, together with farmers' perception of the changes, and identify adaptation options for the Sudano - Sahelian region of West Africa. In this chapter I synthesise the main findings and draw some important conclusions in the context of smallholder farming system in the Sudano - Sahelian zone of West Africa. This will be achieved by discussing the opportunities for different types of farmers to integrate the potential adaptation options identified in Chapters 3, 4 and 5 into their farming system in order to better compensate for the negative effects of current and future climate.

### **6.2. Farm types and their adaptive capacity**

The general view is that Sudano - Sahelian farmers mostly produce millet, sorghum and maize as staple crops with minimum inputs and equipment, resulting in low yield. Productivity

varies strongly due to a large diversity in activities and assets between farmers of the same agro-ecological zone (Sanogo, 2010)

It is important to recognize that Sudano -Sahelian farmers are not all homogeneously poor and also not homogeneously vulnerable to climate change. Some farmers who are engaged in many other activities that may provide a large share of their income (Bryceson, 2003; Nielsen and Reenberg, 2010; Reardon, 1993) are less vulnerable and have a better capacity to cope with adverse climate impacts.

In the study site of interest, farms were split into three groups: a large farm type (6%), a medium farm type (81%) and a small farm type (12%) (Djouara et al., 2006). This typology was based mainly on land holding, ownership of farming assets (plough, seeder, and cultivator) and number of cattle and cropping system (Table 1).

In terms of crops, the area allocated to cotton is larger on large and medium farm types, while for small farms cropping is more focused on sorghum and millet.

In the next paragraph, I use this farm typology to analyse the potential impact of climate on smallholder food self - sufficiency in southern Mali by using the outputs generated in Chapter 5.

Table 6.1: Characteristics of farm types of the cotton zone in southern Mali

|                                       | Large<br>farm<br>type | Medium<br>farm<br>type | Small<br>farm<br>type |
|---------------------------------------|-----------------------|------------------------|-----------------------|
| Household size                        | 34                    | 16                     | 8                     |
| Number of workers                     | 19                    | 9                      | 4                     |
| Heads of oxen                         | 41                    | 8                      | 1                     |
| Ploughing units                       | 3.0                   | 1.4                    | 0.3                   |
| Total cropland area (ha)              | 18.2                  | 10.1                   | 3.9                   |
| Cotton (% of cropland area)           | 42                    | 30                     | 8                     |
| Cotton yield (kg ha <sup>-1</sup> )   | 1082                  | 998                    | 984                   |
| Maize (% of cropland area)            | 6                     | 18                     | 12                    |
| Maize yield (kg ha <sup>-1</sup> )    | 2242                  | 1380                   | 529                   |
| Millet (% of cropland area)           | 21                    | 16                     | 52                    |
| Millet yield (kg ha <sup>-1</sup> )   | 926                   | 703                    | 648                   |
| Sorghum (% of cropland area)          | 31                    | 36                     | 28                    |
| Sorghum yield (kg ha <sup>-1</sup> )  | 1056                  | 801                    | 739                   |
| Cropland area per person (ha)         | 0.54                  | 0.63                   | 0.48                  |
| Cropland area per ploughing unit (ha) | 6.11                  | 7.19                   | 14.81                 |

(Djouara et al., 2006)

1 ploughing unit = 2 oxen + 1 plough

### 6.3. Impact of climate change on smallholder family food self-sufficiency

The impact of climate change on smallholder family food sufficiency was evaluated based on the balance of total energy produced and required at the household level. Total available energy (kcal) was calculated based on cereal production and grain energy content (FAO, 1990). Requirements were determined based on the number of household members and the average daily energy requirement (2450 kcal/person/day) (FAO and INPhO, 1993). We made the assumption that millet and sorghum are similarly affected by climate change, thus the effects of climate change on millet, estimated in Chapter 5 were also applied to sorghum.

Observed average yields of each farm type (Table 6.1) and total land areas were used to determine the current total farm production. The relative impacts of future climate change that were quantified in chapter 5 together with these observed average yields were used to calculate the expected absolute changes in yield under the different scenarios of climate



change and adaptation. For the large farm the adaptation option was based on application of the recommended fertilizer rate. For the medium and small farm types adaptation options were application of the recommended fertilizer rate and planting early in the growing season. Our results showed that, under current conditions, the energy requirements of the large and medium farms were satisfied by on-farm production while the small farm type did not achieve food self-sufficiency (Table 6.2).

Under future climate change, our results indicate that without adaptations, food availability will be reduced for all farm types, but that large farms will still achieve food self – sufficiency (Table 2). The medium and small farm types experience a further decrease in food self-sufficiency. (Butt et al., 2005a) indicated a large impact of future climate change on food security at the country level of Mali resulting in an increase of the risk of hunger from 44% to 64% of the population. We can infer that risk of hunger the household of medium and small farm types will increase, thus according to the FAOs' ranking by the risk of hunger, the country might reach the highest risk category of hunger.

## Chapter 6 – General discussion

Table 6.2: Future climate change impact on the food self-sufficiency of large, medium and small farm types.

|                      |                          |                      | Maize<br>(kg farm <sup>-1</sup> ) | Millet<br>(kg farm <sup>-1</sup> ) | Sorghum<br>(kg farm <sup>-1</sup> ) | Gross<br>margin<br>US\$ pers. <sup>-1</sup><br>day <sup>-1</sup> | Food self-<br>sufficiency<br>(% of<br>kcal) |      |
|----------------------|--------------------------|----------------------|-----------------------------------|------------------------------------|-------------------------------------|--|---|------|
| Farm type            | Cropping practice        | Climate              |                                   |                                    |                                     |  |   |      |
| Large<br>farm        | Current<br>practice      | Baseline             | 2451                              | 4927                               | 7390                                | 0.27   | 176   |      |
|                      |                          | rcp4.5               | 1605                              | 4457                               | 6685                                | 0.22   | 152   |      |
|                      |                          | rcp8.5               | 1538                              | 4542                               | 6163                                | 0.14   | 146   |      |
|                      | Adaptatio<br>n<br>option | F2                   | rcp4.5                            | 1944                               | 6149                                | 9224   | 0.22  | 206  |
|                      |                          |                      | rcp8.5                            | 1939                               | 6063                                | 9094   | 0.21  | 204  |
|                      | Double<br>maize<br>area  | F2                   | rcp4.5                            | 3887                               | 5262                                | 8337   | 0.25  | 208  |
|                      |                          |                      | rcp8.5                            | 3879                               | 5188                                | 8220   | 0.24  | 206  |
|                      | Medium<br>farm           | Current<br>practice  | Baseline                          | 3650                               | 1503                                | 3506   | 0.37  | 103  |
| rcp4.5               |                          |                      | 2679                              | 1393                               | 3251                                | 0.30   | 87  |      |
| rcp8.5               |                          |                      | 2568                              | 1386                               | 3235                                | 0.29   | 85  |      |
| Adaptation<br>option |                          | F2*D1                | rcp4.5                            | 4851                               | 2022                                | 4979   | 0.42  | 141  |
|                      |                          | D1                   |                                   | 4005                               | 1907                                | 4696   | 0.35  | 126  |
|                      |                          | F2                   |                                   | 2986                               | 1477                                | 3447   | 0.22  | 94   |
|                      |                          | F2*D1                | rcp8.5                            | 4840                               | 1979                                | 4874   | 0.44  | 139  |
|                      |                          | D1                   |                                   | 3838                               | 1897                                | 4672   | 0.37  | 124  |
|                      |                          | F2                   |                                   | 2979                               | 1446                                | 3375   | 0.25  | 93   |
| Double<br>maize area |                          | F2                   | rcp4.5                            | 9701                               | 855                                 | 3748   | 0.67  | 169  |
|                      |                          |                      | rcp8.5                            | 9679                               | 837                                 | 3669   | 0.67  | 168  |
| Small<br>farm        |                          | Current<br>practice  | Baseline                          | 693                                | 1802                                | 970  | 0.27  | 41   |
|                      |                          |                      | rcp4.5                            | 678                                | 1746                                | 940  | 0.26  | 40   |
|                      |                          |                      | rcp8.5                            | 650                                | 1654                                | 912  | 0.25  | 38   |
|                      |                          | Adaptation<br>option | F2*D1                             | rcp4.5                             | 1228                                | 2701   | 1571  | 0.44 |
|                      | D1                       |                      |                                   | 1014                               | 2547                                | 1358   | 0.39  | 59   |
|                      | F2                       |                      |                                   | 1144                               | 1870                                | 1088   | 0.34  | 49   |
|                      | F2*D1                    |                      | rcp8.5                            | 1225                               | 2644                                | 1492   | 0.43  | 64   |
|                      | D1                       |                      |                                   | 972                                | 2534                                | 1318   | 0.38  | 57   |
|                      | F2                       |                      |                                   | 1142                               | 1830                                | 1033   | 0.33  | 48   |
|                      | Double<br>maize area     | F2                   | rcp4.5                            | 2456                               | 2389                                | 1235   | 0.55  | 72   |
|                      |                          |                      | rcp8.5                            | 2450                               | 2339                                | 1173   | 0.54  | 71   |

Current practice fertilisation is 65 kg ha<sup>-1</sup> of nitrogen for maize and no application of nitrogen for millet and sorghum. Recommended fertilizer (F2) for maize is 85 kg ha<sup>-1</sup> and 40 kg ha<sup>-1</sup> for millet and sorghum and D1 represents the early planting date. Early and medium planting date with long duration variety was considered as the current planting practice for large and medium farm type respectively and late planting and short duration variety was considered as current practice for small farm type. For each farm type maize area was doubled at the expense of millet and sorghum but without changing the total farm land area.

#### **6.4. Role of planting date in mitigating the impact of climate change and supporting food self-sufficiency for smallholder farmers**

Several studies showed changing planting may help mitigate the negative effects of future climate (Adams et al., 1999; Rosenzweig and Hillel, 1998). Our results show that the effectiveness of planting date as an adaptation option varies according to farm type. Early planting is an important option to achieve food self-sufficiency for the medium and small farm type. Other studies (Soler et al., 2008; Kamara et al., 2009) have also shown the importance of planting date for enhancing crop productivity, but here we show that this option for medium and small farmers is also an essential entry point to stabilize yields in the face of climate change. Farmers need to plant as early as possible to take advantage of the flush of available nitrogen associated with early rains and to avoid weed pressure (Stoop et al., 1981; Vaksman et al., 1996).

It is important to note that delaying planting by about a month does not have too detrimental an effect on crop yields, and that strong differences exist between different crops, as shown in Chapter 3. For instance for maize and sorghum the differences in grain yields between early and medium planting dates are smaller than those between medium and late planting, while for millet early planting was not a good option over the three years of the trial and for all of the three varieties. This means that addressing smallholder food self-sufficiency depends upon the capacity of each farm type to choose appropriately the planting date based on development of the season while taking into account the acceptable planting date window for each individual crop.

#### **6.5. Role of crop variety in meeting smallholder food self-sufficiency**

Our results in Chapter 5 showed that long duration varieties performed better than short duration varieties under climate change. Increases in temperature lead to a reduction of time to flowering, and this reduction affects the production of short duration varieties more strongly than long duration varieties. My experimental results showed that year to year variation in the length of the growing period (Chapter 4) limits the possibility of planting long duration varieties. Furthermore the analysis of farmer perceptions in Chapter 3 showed that many farmers prefer short duration varieties, because they perform better in bad, short growing seasons even though on average they yield less than long duration varieties.

The challenge is to determine up to what date it is best to plant a long duration variety and from which date onwards it is best to plant a short duration variety. In combination with

weather forecast this could help farmers to make a plan, possibly even before the beginning of the rainy season.

The past dynamic of changes in cotton varieties (Fig 6.1) and in cereals (FAO, 2008c; Soumaré et al., 2004) in southern Mali suggests that new varieties continue to be released and adopted, which might offer opportunities to respond to the future climate challenges. But considering the relatively small budget that is invested into crop improvement in most sub-Saharan countries whilst impacts of climate change are projected to worsen by mid-century (Chapter 5), investment in research and development need to be rapid and substantial in order to have a substantial impact on agriculture output on time. Added to this, constraints of restrictions on importing technologies and high regulatory barriers to the release of new technologies, such as the varieties developed by the private sector (World Bank, 2008) should be softened and rapid access by farmers to new varieties should be improved. For instance, improved cultivars exist in Mali but are not widely adopted (Butt et al., 2005b). If they would be adopted agricultural production could significantly increase and make the country's food security situation more resilient in the face of current and future climate.

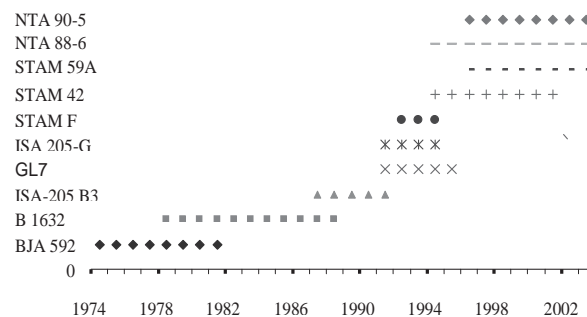


Fig 6.1: Dynamic and diversity of cotton variety used by farmers in the district of Fana from 1974 to 2004 (CMDT database).

### **6.6. Role of application of recommended fertilizer**

If the recommended rate of chemical fertilizer is used, large and medium farm types are food self-sufficient, indicating the importance of chemical fertilizer as an adaptation option. This is in line with our findings at field scale described in Chapter 3. Although farmers are aware of the beneficial effects of chemical fertilizer on crop productivity, access to input markets remains the main constraint. In southern Mali, access to fertilizer mainly depends on growing cotton. As small farm types have a small land area and their cropping systems are oriented to cereals, they have little opportunity to increase the cotton area, leading to limited access to fertilizer as a consequence. Supporting small farm types to cope with impact of climate change through using fertilizer demands facilitating access to credit (Ebi et al., 2011). Moreover, the current government policy of subsidizing fertilizer should give particular attention to the needs of the small farm type.

Besides increasing the amount of fertilizer, there is also still room in the current cropping system to improve fertilizer management practices for all farm types. Achieving this requires the development of an effective means to increase fertilizer use efficiency (Bationo et al., 1998; Buerkert and Lamers, 1999; de Ridder et al., 2004). For instance, several studies showed that the technique of micro-dosing or hill application of fertilizer improved crop yields considerably as well as farmers' income from cereal production (Abdoulaye and Sanders, 2005; Sawadogo-Kaboré et al., 2009; Tabo et al., 2007).

### **6.7. Sustainable intensification to cope with impact of climate change for sustainable food production**

In Chapter 5, our results showed that using chemical fertilizer is a possible option for increasing crop production in order to meet the food requirements of smallholder farmers. In this section, we show that this is possible only if based on sustainable soil fertility management. Indeed, soils in most Sudano - Sahelian regions of West Africa are characterized by low organic matter content, low water holding capacity and inherent low fertility and are prone to degradation (Bationo et al., 2007; Breman and Sissoko, 1998; Giller et al., 2011; Piéri, 1989; Zida, 2011). Unsustainable land use and management involving intensive soil tillage and removal of biomass lead to a decrease of soil organic matter content, deterioration of important soil physical parameters and consequently an increase in soil erosion (Ouedraogo et al., 2006; Sissoko et al., 2013).

In this situation future climate impacts are an extra pressure in addition to the existing problem of degrading soils. The challenge is to find an approach that ensures sustainable production and can help smallholder farmers to cope with the impacts of the future climate.

To overcome soil fertility constraints integrated soil fertility management (ISFM) is a possible starting point for sustainable production (Vanlauwe et al., 2010). In this system, farmers apply soil fertility management practices, improved and diversified crop cultivars in combination with knowledge according to local conditions. This improves fertilizer and organic resource use efficiency and crop production (IFDC, 2008). Organic resources can help to build-up the stock of soil organic carbon, which besides positive effects on soil nutrient supply can also improve soil moisture availability due to increased moisture retention (Nyamangara et al., 2001). The use of organic inputs such as leguminous green manures and the use of crop residues in combination with locally available Tilemsi rock phosphate could be an option for maintaining soil fertility and sustaining crop production that would be within the scope of most smallholder farmers (Pedercini et al., 2012).

#### **6.8. Taking advantage of local weather stations for better crop management**

Poor understanding of the drivers of African climate and their complex interactions is partly due to a severe lack of local weather data (Conway, 2009), which also makes it difficult to plan agricultural activities. There is a need to fill this gap by facilitating the access by farmers to the weather information that is present and improve the weather measurement network in West Africa. Local research must be a multidisciplinary approach where extension services and national weather service collaborate in the establishment of early warning systems. Improvement of the current weather forecasts for these regions is urgently needed, resulting in information that is meaningful for local farmers. For instance, the growth in the use of mobile phone in Mali particularly in rural area constitutes a new channel and a new opportunity to supply climate information. In Kenya, studies showed that it is possible to reach millions of farmers with climate services that support decision-making under a changing climate by using mobile phone (Aker, 2011). The ability to anticipate climate variability and its effects on agriculture production gives farmers the opportunity to better manage climate related risks (Hammer et al., 2001; Hansen et al., 2011). In the short term, an improved weather forecasting system will increase the ability of farmers to take appropriate actions to face adverse weather events. It offers the farmer an opportunity to improve the timing and management of inputs in ways that reduce financial and production risks.

### **6. 9. Room for increasing the cropped area of maize**

The cropped area of maize has increased during the past 20 years in Mali but it is still less than that of sorghum and millet. In Chapter 3, the gross margin was calculated at field level for each of the crops, and this indicated that if we fertilize maize, the income per ha is larger than that of fertilized millet. This indicates that there is room to increase the area allocated to maize. The principal constraint of increasing the area under maize is related to access to fertilizer. The silent revolution of maize production that started in the 1960s was driven by farmers' increased adoption of fertilizer and its increased application rate (Foltz et al., 2012), which was strongly supported by the cotton company. This adoption resulted in decreasing areas under millet and sorghum (Soumaré et al., 2004).

The current difficult economic situation of the Cotton Company is resulting in more limited access to inputs for farmers, which could also limit the further expansion of maize. An alternative solution could be the establishment of a credit system which is different from the current cotton company system to ease the access to inputs. Our results showed that increasing the area under maize is an option to meet family food needs and also to improve family income (Table 2). For the small farmer type, even if the increase of maize area did not cover the full family food needs, it did improve their food availability on average.

### **6.10. The planter `semoir NAFAMA`: an option for saving time**

Smallholder farmers without animal traction face a major challenge to be able to plant with the first useful rain in order to maximize rainfall use efficiency and avoid the recurrent drought at end of the season. Taking advantage of early planting is not possible for all farmers, especially for the smaller farms. A promising alternative is to improve labour use efficiency, because farming in the region, as in most of sub-Saharan Africa, is based on manual labour while making use of rudimentary equipment. Furthermore, as the rainy season is short in the Sudano - Sahelian zone and the beginning of the rainy season is in most cases uncertain, farmers are under pressure to plant their land in a very short period of time, which creates a peak labour shortage. In this context improving labour use efficiency is a critical entry point to achieve early planting.

One important option to address this constraint is by intermediate, easy access technology (Kouyaté et al., 2000; Pedercini et al., 2012; World Bank, 2008). Indeed in most of sub-Saharan Africa, technologies based on small scale mechanization (planter, plough, scarificator) in combination with draught animals has been successful (CTA, 1997). Many

farmers have rapidly adopted this technology because of time saving (FAO, 2008a). However, since its first introduction in the 1970s, this type of equipment has evolved only marginally. In Mali, there have been attempts to introduce planting machines, but this initiative failed and was not adopted by farmers because the equipment was difficult to manufacture by local blacksmiths. Research undertaken recently by the ``programme coton de NTarla`` and supported by CMDT (Compagnie Maliennne pour le Developpement du Texile) has resulted in the design and development of a planting machine called the `Semoir NAFAMA' (Fig 6.3), mainly aimed at planting cotton, millet, sorghum and maize. At the moment the `Semoir NAFAMA' has been tested for planting cotton (Fig 6.4) and for application of chemical fertilizer (Fig 6.5).

Research has shown that `Semoir NAFAMA' can plant cotton according to the agricultural research recommendations (Table 3). With the `Semoir NAFAMA' the farmer can reduce the time needed for planting by 35-40%, resulting in reduced human drudgery and better timeliness of operations which may also allow to bring more land into cultivation (FAO, 2008a). In addition, it can apply and bury chemical compound fertilizer and urea while in the current situation, farmer apply chemical fertilizer by spreading.

Although effects of increased nitrogen use efficiency due to the planter have not yet been documented, but several studies have shown a large increase of crop yield due to the localized application of chemical fertilizer (Abdoulaye and Sanders, 2005; Sawadogo-Kaboré et al., 2009; Tabo et al., 2007). With the `Semoir NAFAMA' large sized farms will have the possibility to plant the totality of their land at an early planting date and medium and small sized farm types will likely have the opportunity to plant a large part of their land at the beginning of the rainy season. Despite the opportunity offered by this technology, the current challenge is its access for farmers. Given the low income of smallholder farmer, access to this technology should be facilitated by collaboration between research and extension workers for the dissemination and by local policy support through subsidies or credit services.

Table 6.3: Performance of the planter (semoir NAFAMA) compared with the reference (recommended practice).

|               | Cotton seed<br>(grain kg ha-1) | Chemical compound<br>fertilizer (kg ha-1) | Urea<br>(kg ha-1) | Time of planting<br>(hour ha-1) |
|---------------|--------------------------------|---|-------------------|---------------------------------|
| Reference     | 14                             | 150                                       | 50                | 6.8                             |
| Semoir NAFAMA | 17.2                           | 152                                       | 53                | 4.4                             |
| STD           | 0.9                            | 3.7                                       | 2.9               | 0.21                            |
| CV %          | 6.2                            | 2.4                                       | 5.5               | 4.8                             |





Fig 6.3: Planter “Semoir NAFAMA”

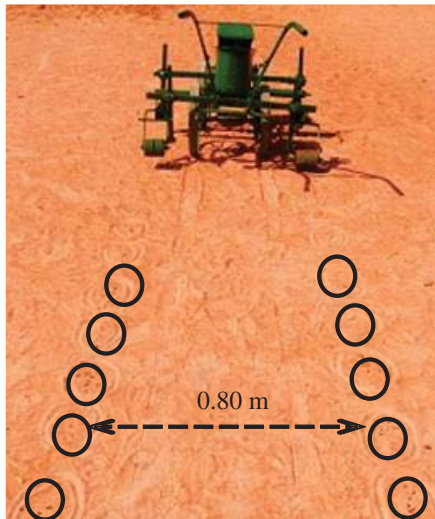


Fig 6.4: Planting of two lines  
with 'semoir NAFAMA''

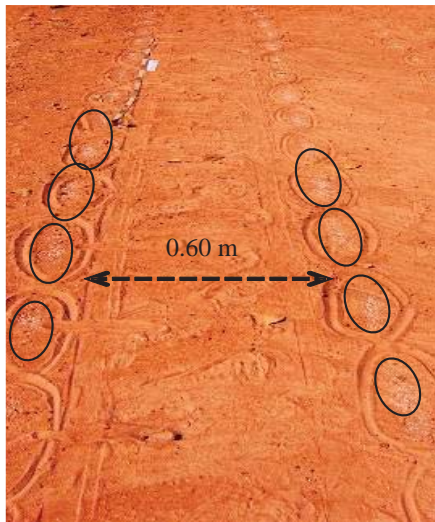


Fig 6.5: Application of fertilizer  
with planter "Semoir  
NAFAMA''

## **Conclusion**

In this study I have quantified how climate variability constrains agricultural production in southern Mali, and how climate change can exacerbate this situation. Climate variability is a key driver for rain fed agriculture, the most common agricultural practice in southern Mali, and average total rainfall is not necessarily a good indicator of a good rainy season or associated with good crop production. The determining factor is the within season rainfall distribution. A key component of this distribution is the start of rainy season, delay of which can lead to delays in cropping practices and reduced production.

After having analyzed past climate of southern Mali, I have had opportunity to understand the perception of farmers from the village of N’Goukan and Try on climate change and variability. It is clear that for farmers climate change is a reality as it is scientifically proven. Training of farmers on important aspects of weather and its variability, and especially on the onset of the rains, is critical to enhancing farmers’ adaptive capacity to climate change. The main challenge remains to get farmers informed up to a level that they will take into account weather information in their management decisions for their production system. This will depend on efficient weather information systems, and information in a form that is readily usable for farmers.

Through a field experiment on research station I tried to find out different technical options that may be readily available to farmers to adapt to the intra-annual climate variability. I found that adaptation to climate variability is not a straightforward choice for early or late planting, nor for long or short duration varieties. For the best choice, information on planting date and variety needs to be combined and based on the nature of the current weather. Drought risk can be avoided by better decisions on planting date (do not plant too early or too late) in combination with the choice of varieties that are adapted to current rainfall.

Beyond the challenges related with the present weather, a major concern is to quantify the impact of future climate on crop production and to provide appropriate adaptation solutions to ensure food security for the region. Although the negative impacts of future climate on crop production are substantial, I showed that coping with climate change appears to be possible. If current crop management is improved by avoiding delays in planting, application of recommended fertilization rates and use of best performing crop varieties yield losses due to climate change can be compensated and even turned into a yield increase compared with current yields.

In conclusion, understanding of past, current and future climate change and variability is crucial to address the food shortages in Sudano - Sahelian zone of West Africa. This thesis

has quantified the negative effect of climate change and variability on crop yields and on the food self-sufficiency of smallholder farms, and identified some adaptation strategies which in some cases are based on adopting better cropping management strategies. I hope that the findings reported in this thesis will be useful to scientists, policy maker and extension services in coping with climate change and variability in southern Mali.

## References

## References

- Abdoulaye, T. and Sanders, J.H., 2005. Stages and determinants of fertilizer use in semiarid African agriculture: the Niger experience. *Agricultural Economics*, 32(2): 167-179.
- Abrol, Y.P. and Ingram, K.T., 1997. Les effets de la hausse des températures diurnes et nocturnes sur la croissance et les rendements de certaines plantes cultivées, chapitre 6. In: FAO and POLYTECHNICA (Editors), *Changements du climat et production agricole. Agriculture mondiale: Horizon 2010*, Rome, pp. 472.
- Adams, R.M., Hurd, B.H. and Reilly, J., 1999. *Agriculture and Global Climate Change: A Review of Impacts to U.S. Agricultural Resources*, Pew Center on Global Climate Change, Washington DC.
- Adger, W.N., Huq, S., Brown, K., Conway, D. and Hulme, M., 2003. Adaptation to climate change in the developing world. *Progress in development studies*, 3(3): 179-195.
- Agele, S., 2006. Weather and seasonal effects on growth, seed yield and soluble carbohydrate concentrations in selected maize cultivars in the humid areas of Nigeria. *African Journal of Agricultural Research*, 4(1): 101-110.
- Akbar, M., Shakoor, M., Hussain, A. and Sarwar, M., 2008. Evaluation of maize 3-way crosses through genetic variability, broad sense heritability, characters association and path analysis *Journal of Agricultural Research*, 46(1): 39-45.
- Aker, J.C., 2011. Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, 42(6): 631-647.
- Akponikpè, P.B.I., Gérard, B., Michels, K. and Biielders, C., 2010. Use of the APSIM model in long term simulation to support decision making regarding nitrogen management for pearl millet in the Sahel. *European Journal of Agronomy*, 32(2): 144-154.
- Alberge, J., Carbonnel, J.P. and Vaugelade, J., 1985. Aléas climatiques et production agricole: le coton au Burkina Faso. *Ecologie Appliquée*, 6(3): 199-211.
- Andrews, D.J., 1973. Effects of date of sowing on photosensitive Nigerian sorghums. *Experimental Agriculture*, 9(04): 337-346.
- Apata, T.G., Samuel, K. and Adeola, A., 2009. Analysis of climate change perception and adaptation among arable food crop farmers in South Western Nigeria, Contributed paper prepared for presentation at the international association of agricultural economists, Beijing, China, August 16.
- Archer, D.R., 1981. Rainfall sequences in northern Malawi. *Weather*, 36: 2-9.
- Assefa, Y., Staggenborg, S.A. and Prasad, V.P., 2010. Grain sorghum water requirement and responses to drought stress: a review. *Crop Management*, 9(1): 0-0.
- Ati, O., Stigter, C. and Oladipo, E., 2002. A comparison of methods to determine the onset of the growing season in northern Nigeria. *International Journal of Climatology*, 22(6): 731-742.
- Bacci, L., Cantini, C., Pierini, F., Maracchi, G. and Reyniers, F.N., 1999. Effects of sowing date and nitrogen fertilization on growth, development and yield of a short day cultivar of millet (*Pennisetum glaucum* L.) in Mali. *European Journal of Agronomy*, 10(1): 9-21.
- Balme, M., Vischel, T., Lebel, T., Peugeot, C. and Galle, S., 2006. Assessing the water balance in the Sahel: Impact of small scale rainfall variability on runoff: Part 1: Rainfall variability analysis. *Journal of Hydrology*, 331(1-2): 336-348.
- Barrabe, A., Rapidel, B., Sissoko, F., Traore, B. and Wery, J., 2007. Elaboration and test of a decision rule for the application of

## References

- mepiquat chloride on cotton in Mali. *European Journal of Agronomy*, 27: 197 - 204.
- Barrios, S., Ouattara, B. and Strobl, E., 2008. The impact of climatic change on agricultural production: Is it different for Africa? *Food Policy*, 33(4): 287-298.
- Barron, J., Rockström, J., Gichuki, F., Hatibu, N. and Hughes, D., 2003. Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and Forest Meteorology*, 117: 23-37.
- Bationo, A. and Buerkert, A., 2001. Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, 61(1-2): 131-142.
- Bationo, A., Christianson, C.B. and Mokwunye, A.U., 1989. Soil fertility management of the pearl millet-producing sandy soils of Sahelian West Africa: The Niger experience. Soil, crop, and water management systems for rainfed agriculture in the Sudano-Sahelian zone. p. 159-168, Int. Workshop, ICRISAT Sahelian Center, Niamey, Niger, 11-16 Jan 1987, ICRISAT Patancheru, A.P. 502 324, India.
- Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B. and Kimetu, J., 2007. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems*, 94(1): 13-25.
- Bationo, A., Lompo, F. and Koala, S., 1998. Research on nutrient flows and balances in West Africa: state-of-the-art. *Agriculture, ecosystems & environment*, 71(1): 19-35.
- Bationo, A. and Ntare, B., 2000. Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi-arid tropics, West Africa. *Journal of Agricultural Science*, 134(3): 277-284.
- Bayala, J., Sileshi, G.W., Coe, R., Kalinganire, A., Tchoundjeu, Z., Sinclair, F. and Garrity, D., 2012. Cereal yield response to conservation agriculture practices in drylands of West Africa: a quantitative synthesis. *Journal of Arid Environments*, 78: 13-25.
- Bazile, D. and Soumare, M., 2004. Gestion spatiale de la diversité variétale en réponse à la diversité écosystémique : le cas du sorgho [*Sorghum bicolor* (L) Moench] au Mali. *Cahiers Agricultures*, 13: 1-8.
- Beiragi, M.A., Khorasani, S.K., Shojaei, S.H., Dadresan, M., Mostafavi, K. and Golbashy, M., 2011. A study on effects of planting dates on growth and yield of 18 corn hybrids (*Zea mays* L.). *American Journal of Experimental Agriculture*, 1(3): 110-120.
- Bello, O.B., Abdulmalik, S.Y., Ige, S.A., Mahamood, J., Oluleye, F., Azeez, M.A. and Afolabi, M.S., 2012. Evaluation of Early and Late/Intermediate Maize Varieties for Grain Yield Potential and Adaptation to a Southern Guinea Savanna Agro-ecology of Nigeria. *International Journal of Plant Research*, 2(2): 14-21.
- Bennett, A.J., Bending, G.D., Chandler, D., Hilton, S. and Mills, P., 2012. Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations. *Biological Reviews*, 87(1): 52-71.
- Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P., 2007. Africa. In: Parry M, Canziani O, Palutikof J, van der Linden P, Hanson C (eds) *Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, pp 433-467.
- Breman, H., 2002. Soil Fertility and Farmers' Revenue: Keys to Desertification Control. In: H. Shimizu (Editor), *Integration and regional researches to combat desertification. Present state and future prospect*. The 16th Global Environment CGER/NIES, Tsukuba, pp. 26 - 41.
- Breman, H. and Sissoko, K., 1998. *L'intensification agricole au Sahel*. Paris, Karthala Editions 996 pp.

## References

- Brooks, N., 2004. Drought in the African Sahel: long term perspectives and future prospects. Tyndall Centre for Climate Change Research, Norwich, Working Paper, 61: 31.
- Brouwer, J., Fussel, L.K., Hermann, L., 1993. Soil and crop growth microvariability in the West African semi-arid tropics: a possible risk reducing factor for subsistence farmers. *Agriculture, Ecosystems and Environment*, 45: 229- 238.
- Buerkert, A. and Lamers, J.P.A., 1999. Soil erosion and deposition effects on surface characteristics and pearl millet growth in the West African Sahel. *Plant and Soil*: 239- 253.
- Burke, J.J., 1990. High temperature stress and adaptation in crops. In: R.G. Alscher and J.R. Cummings (Editors), *Stress Response in Plants: Adaptation and Acclimation Mechanisms*, Wiley-Liss, New York, pp. 295-309.
- Butt, T.A., McCarl, B.A., Angerer, J., Dyke, P.T. and Stuth, J.W., 2005a. The economic and food security implications of climate change in mali. *Climatic Change*, 68(3): 355-378.
- Butt, T.A., McCarl, B.A. and Kergna, A.O., 2005b. Policies for reducing agricultural sector vulnerability to climate change in Mali. *Climate Policy*, 5 581-596.
- Butt, T.A., McCarl, B.A. and Kergna, A.O., 2006. Policies for reducing agricultural sector vulnerability to climate change in Mali. *Climate Policy*, 5: 583-598.
- Carberry, P.S., Campbell, L.C. and Bidinger, F.R., 1985. The growth and development of pearl millet as affected by plant. *Field Crops Research*, 11(0): 193-205.
- Carney, J. and Elias, M., 2006. Revealing gendered landscapes: indigenous female knowledge and agroforestry of African she. *Canadian Journal of African Studies*, 40: 235-267.
- CEDEAO-ClubSahel/OCDE/CILSS, 2008. Climate and climate change. The atlas on regional integration in West Africa. Environment series, p.13.
- CGIAR, 2009. Climate, Agriculture and Food Security: A Strategy for Change. Consultative Group on International Agricultural Research (CGIAR), p. 56.
- Challinor, A., Wheeler, T., Garforth, C., Craufurd, P. and Kassam, A., 2007. Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic Change*, 83(3): 381-399.
- Chandrashekar, A. and Satyanarayana, K.V., 2006. Disease and pest resistance in grains of sorghum and millets. *Journal of Cereal Science*, 44(3): 287-304.
- Chaudhry, R. and Guitchounts, A., 2003. Cotton Facts. Comité consultatif international du coton (ICAC). Washington, D.C., États-Unis d'Amérique, 158 p.
- Chuku, C.A. and Okoye, C., 2009. Increasing resilience reducing vulnerability in sub-Saharan African agriculture: strategies for risk coping and management. *African Journal of Agricultural Research*, 4: 1524-1535.
- CILSS, 1987. Projet lutte Integree. compte rendu de la reunion technique annuelle, 2-7 Fevrier, Gambia
- Cleaver, K.M. and Schreiber, G.A., 1994. Supplement to reversing the spiral: The population, agriculture, and environment nexus in Sub-Saharan Africa. Washington DC: World Bank.
- Clement, J.C. and Leblanc, J.M., 1980. Prospection des mils pénicillaires, sorgho et graminées mineures en Afrique de l'Ouest. Campagne 1978. République du Mali. International Board for Plant Genetic Ressources, Orstom, Paris
- Cleveland, D. and Soleri, D., 2007. Farmer knowledge and scientist knowledge in sustainable agricultural development: ontology, epistemology and praxis. *Local science vs global science: approaches to indigenous knowledge in international development.*, Berghahn, New York.

## References

- Club du Sahel, 2011. Perspective Ouest-Africaines: Peuplement, Marche et Securite Alimentaire. Club du sahel et de l'Afrique de l'Ouest, 4: 1-7.
- Cochemé, J. and Franquin, P., 1967. A study of the agroclimatology of the semiarid area south of the Sahara in West Africa. FAO/UNESCO.
- Conen, F., Leifeld, J., Seth, B. and Alewell, C., 2006. Warming mineralises young and old soil carbon equally. *Biogeosciences*, 3(4): 515-519.
- Conijn, J.G., Hengsdjik, H., Rutgers, B. and Jonschaarp, R.E.E., 2011. Mapping maize yield variability in Mali. Plant Research International, Wageningen UR, Business Unit Agrosystem Reasearch Report 375.
- Conley, S.P. and Wiebold, W.J., 2003. Grain sorghum response to planting date. *Crop Management*, doi:10.1094/CM-2003-0204-01-RS
- Conway, G., 2009. The science of climate change in Africa: impacts and adaptation. Grantham Institute for Climate Change Discussion Paper, 1: 24.
- Cook, C., Reason, C.J. and Hewitson, B.C., 2004. Wet and dry spells within particularly wet and dry summers in the South African summer rainfall region. *Climate Research*, 26(1): 17-31.
- Cooper, P.J.M., Dimes, J., Rao, K.P.C., Shapiro, B., Shiferaw, B. and Twomlow, S., 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems and Environment*, 126: 24-35.
- Coulibaly, S.B., 1995. Rapport analytique du mil: utilisation de la date et de la densite de semis comme technique de criblage du mil pour la resistance a la secheresse IER-Mali: P. 37-47.
- Crane, T.A., Roncoli, C. and Hoogenboom, G., 2011. Adaptation to climate change and climate variability: The importance of understanding agriculture as performance. *NJAS - Wageningen Journal of Life Sciences*, 57(3-4): 179-185.
- Craufurd, P., Mahalakshmi, V., Bidinger, F., Mukuru, S., Chanterreau, J., Omanga, P., Qi, A., Roberts, E., Ellis, R. and Summerfield, R., 1999. Adaptation of sorghum: characterisation of genotypic flowering responses to temperature and photoperiod. *Theoretical and applied genetics*, 99(5): 900-911.
- Craufurd, P.Q. and Aiming, Q., 2001. Photothermal adaptation of sorghum (*Sorghum bicolor*) in Nigeria. *Agricultural and Forest Meteorology*, 108: 199-211.
- Craufurd, P.Q. and Bidinger, F.R., 1988. Effect of the duration of the vegetative phase on shoot growth, development and yield in pearl millet [*Pennisetum americanum* (L.) Leake]. *Journal of Experimental Botany*, 38: 124-139.
- Craufurd, P.Q. and Bidinger, F.R., 1989. Potential and realized yield in pearl millet (*Pennisetum americanum*) as influenced by plant population density and life-cycle duration. *Field Crops Research*, 22(3): 211-225.
- CTA, 1997. Intégrer la mécanisation dans les stratégies de développement durable de l'agriculture Synthèse et recommandations du séminaire du CTA Ouagadougou, Burkina Faso, 24-29 novembre 1997.
- Dai, A., 2001. Global precipitation and thunderstorm frequencies. Part II: Diurnal variations. *Journal of Climate*, 14(6): 1112-1128.
- Dai, A., Lamb, P.J., Trenberth, K.E., Hulme, M., Jones, P.D. and Xie, P., 2004. The recent Sahel drought is real. *International Journal of Climatology*, 24(11): 1323-1331.
- Dai, A. and Trenberth, K.E., 2004. The diurnal cycle and its depiction in the Community Climate System Model. *Journal of Climate*, 17(5): 930-951.
- de Graaff, J., Kessler, A. and Nibbering, J.W., 2011. Agriculture and food security in selected countries in Sub-Saharan Africa: diversity in trends and opportunities. *Food Security*, 3(2): 195-213.



## References

- de Ridder, N., Breman, H., van Keulen, H. and Stomph, T.J., 2004. Revisiting a 'cure against land hunger': soil fertility management and farming systems dynamics in the West African Sahel. *Agricultural Systems*, 80(2): 109-131.
- Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T. and Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19(2): 248-255.
- Derks, E. and Lusby, F., 2006. Mali shea kernel value chain case study, microreport 50, In: ACIDI/VOCA (Accelerated Microenterprise Advancement Project Business Development Services Knowledge and Practice Task Order), Washington, DC.
- Desanker, P. and Magadza, C., 2011. Africa. In: McCarthy J, Canziani O, Leary N, Dokken D, White K (eds) *Climate change 2001: impacts, adaptation and vulnerability. Contribution of working group II to the third assessment report of the intergovernmental panel climate change*. Cambridge University Press, Cambridge and New York, NY, 1032 pp.
- Deveze, J.C., 2006. Le devenir des agricultures cotonnières: Cas du Mali, AFD, Mali.
- Diarra, B., Lidon, B., Valet, S. and Traoré, S.B., 1987. Zonage des potentialités agropédoclimatiques du Mali. . In: ICRISAT (Editor), *Les cultures associées au Mali*. ICRISAT, Bamako, pp. 17-28.
- Diggs, D.M., 1991. Drought experience and perception of climatic change among Great Plains farmers. *Great Plains Research: A Journal of Natural and Social Sciences*: 1.
- Dingkuhn, M., Kouressy, M., Vaksman, M., Clerget, B. and Chantereau, J., 2008. A model of sorghum photoperiodism using the concept of threshold-lowering during prolonged appetence. *European Journal of Agronomy*, 28(2): 74-89.
- Diop, M., 1996. A propos de la durée de la saison des pluies au Sénégal. *Sécheresse*, 7: 7-15.
- Djouara, H., Bélières, J.F. and Kébé, D., 2006. Les exploitations agricoles familiales de la zone cotonnière du Mali face à la baisse des prix du coton-graine. *Cahiers Agricultures*, 15(1): 1-8.
- Do, F. and Winkel, T., 1993. Morpho-physiologie de la résistance à la sécheresse, in : S. Hamon (Ed.), *Le mil en Afrique. Diversité génétique et agro-physiologie : potentialités et contraintes pour l'amélioration et la culture*, Éditions Orstom. 187-204.
- Dodd, D.E.S. and Jolliffe, I.T., 2001. Early detection of the start of the wet season in semiarid tropical climates of Western Africa. *International Journal of Climatology*, 21: 1251-1262.
- Drechsel, P., Gyiele, L., Kunze, D. and Cofie, O., 2001. Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. *Ecological Economics*, 38(2): 251-258.
- Easterling, W., Aggarwal, P., Batima, P., Brander, K., Bruinsma, J., Erda, L., Howden, M., Tubiello, F., Antle, J., Baethgen, W.,, 2007. Food, fibre and forest products. *Climate Change 2007. Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. In: Parry, M.L., co-editors (Eds.). Cambridge University Press, Cambridge, UK, pp. 273-313.
- Ebi, K.L., Padgham, J., Doumbia, M., Kergna, A., Smith, J., Butt, T. and McCarl, B., 2011. Smallholders adaptation to climate change in Mali. *Climatic Change*, 108(3): 423-436.
- Edmeades, G.O., Bolanos, J., Hernadez, M. and Bello, S., 1993. Causes of silk delay in lowland tropical maize population. *Crop Science*, 33: 1029-1035.
- Egharevba, P.N., 1979. *Agronomic Practices for Improved Millet Production*. Samaru Miscellaneous Paper, 90: Institute for Agricultural Research, Samaru, Zaria, Nigeria.

## References

- Ehui, S. and Pender, J., 2005. Resource degradation, low agricultural productivity, and poverty in sub-Saharan Africa: pathways out of the spiral. *Agricultural Economics*, 32(s1): 225-242.
- ESPGRN, 1998. Annuaire statistique Suivi-Evaluation-Permanent. Campagne 1997. Equipe Système de Production et Gestion des Ressources Naturelles, Sikasso, Mali.
- FAO, 1990. Protein quality evaluation. Report of a Joint FAO/WHO Expert Consultation, Bethesda, MD, USA, 4-8 December 1989. Rome, FAO. 66 pp.
- FAO, 2003. Responding to Agricultural and Food Insecurity Challenges Mobilising Africa to Implement Nepad Programmes. Conference of Ministers of agriculture of the African Union. FAO, Maputo, Mozambique.
- FAO, 2006. World Reference Base for Soil Resources. A framework for international classification, correlation and communication. World Soil Resources Reports 103. FAO, Rome.
- FAO, 2008a. Agricultural mechanization in Africa. Time for action: planning investment for enhanced agricultural productivity. Report of an expert group meeting jointly held by FAO and UNIDO in Vienna on 29-30 November 2007. Rome, FAO. 26 pp.
- FAO, 2008b. Climate and Climate change: Atlas on Regional integration in West Africa. Environments series. ECOWAS-SWAC/OECD, Abuja - Nigeria, 24 pp.
- FAO, 2008c. West African catalogue of plant species and varieties.
- FAO, 2012. Twenty-seventh FAO Regional Conference for Africa. ARC/12/REP Rev.1, Brazzaville Congo 23-27 April 2012
- FAO and INPhO, 1993. Rice in human nutrition, Rome.
- Fischer, G., Shah, M., Tubiello, F. and VanVelhuizen, H., 2005. Socio-economic and climate change impacts on agriculture: An integrated assessment, 1990-2080. *Philosophical Transactions of the Royal Society. Biological Sciences*, 360: 2067-2083.
- Fischer, G., Shah, M., van Velthuisen, H. and Nachtergaele, F.O., 2001. Global agro-ecological assessment for agriculture in the 21st century: Methodology and Results. *International Institute for Applied Systems Analysis, Vienna*, 119 pp.
- Fisher, G., Frouhberg, K., Parry, M.L. and Rosenzweig, C., 1997. Les effets potentiels du changement de climat sur la production et la sécurité alimentaires mondiales. In: FAO and POLYTECHNICA (Editors), *Changements du climat et production agricole. Agriculture mondiale: Horizon 2010*, Rome, pp. 472.
- Fok, M., Kone, M., Djouara, H. and Dolo, A., 2000. Combined and changing effects of market incentives, technical innovations and support on maize production in Southern Mali. Communication associated to a poster presented to the IAAE 24 th International Conference, Berlin (Germany).
- Foliard, A., Traore, P.C.S., Vaksman, M. and Kouressy, M., 2004. Modeling of sorghum response to photoperiod: a threshold-hyperbolic approach. *Field Crops Research*, 89: 59-70.
- Foltz, J.D., Aldana, U.T. and Laris, P., 2012. The Sahel's Silent Maize Revolution: Analyzing Maize Productivity in Mali at the Farm-level, National Bureau of Economic Research.
- Francis, C.A., 1986. Future perspectives of multiple cropping. *Multiple Cropping Systems*. C A. Francis (ed). Macmillan, New York. pp: 351-370.
- Fraser, E.D.G., Dougill, A.J., Hubacek, K., Quinn, C.H., Sendzimir, J. and Termansen, M., 2011. Assessing vulnerability to climate change in dryland livelihood systems: Conceptual challenges and interdisciplinary solutions. *Ecology and Society*, 16(3): 01.
- Fussell, L.K., Bidinger, F.R. and Bieler, P., 1991. Crop physiology and breeding for drought tolerance: research and development. *Field Crops Research*, 27(3): 183-199.

## References

- Galvin, K.A., Boone, R.B., Smith, N.M. and Lynn, S.J., 2001. Impacts of climate variability on East African pastoralists: linking social science and remote sensing. *Climate Research*, 19(2): 161-172.
- GIEC, 2007. Bilan 2007 des changements climatiques. Contribution des Groupes de travail I, II et III au quatrième Rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat, Genève, Suisse, 103 pp.
- Gigou, J., Traoré, K., Giraudy, F., Coulibaly, H., Sogoba, B. and Doumbia, M., 2006. Aménagement paysan des terres et réduction du ruissellement dans les savanes africaines. *Cahiers Agricultures*, 15: 116-122.
- Giller, K.E., Tittonell, P., Rufino, M.C., van Wijk, M.T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E.C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W.J., Sanogo, O.M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'ungu, J., Mwale, M., Nwaga, D., Pacini, C. and Vanlauwe, B., 2011. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems*, 104(2): 191-203.
- Graef, F. and Haigis, J., 2001a. Spatial and temporal rainfall variability in the Sahel and its effects on farmers' management strategies. *Journal of Arid Environments*, 48(2): 221-231.
- Graef, F. and Haigis, J., 2001b. Spatial and temporal rainfall variability in the Sahel and its effects on farmers' management strategies. *Journal of Arid Environments*, 48: 221-231.
- Haddeland, I., Heinke, J., Voß, F., Eisner, S., Chen, C., Hagemann, S. and Ludwig, F., 2012. Effects of climate model radiation, humidity and wind estimates on hydrological simulations. *Hydrology and Earth System Sciences*, 16(2): 305-318.
- Hammer, G.L., Hansen, J.W., Phillips, J.G., Mjelde, J.W., Hill, H., Love, A. and Potgieter, A., 2001. Advances in application of climate prediction in agriculture. *Agricultural Systems*, 70(2-3): 515-553.
- Hansen, J.W., Mason, S.J., Sun, L. and Tall, A., 2011. Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. *Experimental Agriculture*, 47(2): 205-240.
- Hartwell, L., Allen, J.R., Baker, J.T. and Boote, J.K., 1997. L'effet fertilisant du CO<sub>2</sub>: production et rétention accrues d'hydrates de carbone en termes de rendement en biomasse et en grain. In: *FAO and POLYTECHNICA (Editors), Changements du climat et production agricole. Agriculture mondiale: Horizon 2010*, Rome, pp. 472.
- Hazelton, P. and Murphy, B., 2007. Interpreting soil test results: What do all the number means? CSIRO publishing, Collingwood, Victoria, Australia, 160 pp.
- Hoogmoed, W.B. and Klaij, M.C., 1988. Tillage and Planting Strategies for Sandy Soils in Niger, West Africa. In: *Proceedings of the International Conference on Dryland Farming*, August 15-19, 1988, Amarillo/Bushland, Texas U. S.A.
- Hope, K.R., 2009. Climate change and poverty in Africa. *International Journal of Sustainable Development & World Ecology*, 16(6): 451-461.
- Hulme, M., Doherty, R., Ngara, T., New, M. and Lister, D., 2001. African climate change: 1900-2100. *Climate Research*, 17(2): 145-168.
- Hussain, N., Khan, M. and Baloch, M., 2011. Screening of maize varieties for grain yield at Dera Ismail Khan. *Journal of Animal and Plant Science*, 21(3): 626-628.
- IER/CMDT/OHVN, 1998. Mémoire de réunion de concertation sur la baisse de rendement de la variété NTA 88-6 au cours de la campagne 97/98, Institut d'Economie Rurale, N'Tarla, Mali.
- IFDC, 2008. Agroecological principles of Integrated Soil Fertility Management: A guide with special reference to Sub-Saharan Africa. Technical Bulletin IFDC-T-73.

## References

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- Ingram, K.T., Roncoli, M.C. and Kirshen, P.H., 2002. Opportunities and constraints for farmers of west Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. *Agricultural Systems*, 74(3): 331-349.
- IPCC, 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* In: J.T. Houghton, Ding, Y. Griggs, D.J. Noguer, M. van der Linden, P.J. Dai, X. Maskell, K. Johnson, C.A. (Editor). Cambridge University Press, Cambridge and New York pp. 881.
- IPCC, 2007a. *Climate change 2007: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 976 pp.
- IPCC, 2007b. *Summary for Policymakers*. In: S. Solomon, Qin, D., Manning, M., Chen, Z., Marquis, M. Averyt, K.B., Tignor, M., and H.L. Miller (Editors), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge United Kingdom and New York
- IPCC, 2013. *Summary for Policymakers*. In: T.F. Stocker et al. (Editors), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- IRCT, 1969. *Expérimentation régionale cotonnière. Rapport d'activité, Station de N'Tarla, République du Mali*.
- ITC, 2011. *Coton et changement climatique : Impacts et options de réduction et d'adaptation*. Genève : ITC, 2011. xii, 36 p.
- Jagtap, S. and Abamu, F., 2003. Matching improved maize production technologies to the resource base of farmers in a moist savanna. *Agricultural Systems*, 76(3): 1067-1084.
- Jalloh, A., Nelson, G., Thomas, T., Zougmore, R.B. and Roy-Macauley, H., 2013. *West African agriculture and climate change: A comprehensive analysis*. IFPRI.
- Jones, P.G. and Thornton, P.K., 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change*, 13(1): 51-59.
- Kamara, A., Y. Friday, E., David, C. and Lucky, O.O., 2009. Planting date and cultivar effects on grain yield in dryland corn production. *Agronomy Journal*, 101: 91-98.
- Kamara, A.Y., Menkir, A., Badu-Apraku, B. and Ibikunle, O., 2003. Reproductive and stay-green trait responses of maize hybrids, improved open-pollinated cultivars and farmers' local cultivars to terminal drought stress. *Maydica*, 48: 29-37.
- Kanté, S., 2001. *Gestion de la fertilité des sols par classe d'exploitation au Mali-Sud. Documents sur la Gestion des Ressources Tropicales. Doctorat Thesis, Wageningen University and Research Centre Departement of Plant Science*, 225 pp.
- Kassam, A.H., Dagg, M., Kowal, J.M. and Khadr, F.H., 1976. Improving food crop production in the Sudan Savanna Zone of Northern Nigeria. *Outlook on Agriculture*, 8: 341-347.
- Keating, B.A., Carberry, P., Hammer, G., Probert, M.E., Robertson, M., Holzworth, D., Huth, N., Hargreaves, J., Meinke, H. and Hochman, Z., 2003. An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy*, 18(3): 267-288.
- Kirschbaum, M.U.F., 2000. Will changes in soil organic carbon act as a positive or negative feedback on global warming? *Biogeochemistry*, 48(1): 21-51.
- Kitinya, K.T., Onwonga, R.N., Onyang, C., Mbuvi, J.P. and Kironchi, G., 2012. *Climate Change and Variability: Farmers' Perception, Experience*

## References

- and Adaptation Strategies in Makueni County, Kenya. *Asian Journal of Agriculture and Rural Development*, 2(3): 411-421.
- Knorr, W., Prentice, I.C., House, J.I. and Holland, E.A., 2005. Long-term sensitivity of soil carbon turnover to warming. *nature*, 433(7023): 298-301.
- Kouressy, M., 2002. Etude de la duree du cycle des sorghos au Mali. Comparaison avec la duree de la saison des pluies. Evolution sur les 20 dernieres annees DEA Thesis, Universite du Mali, Bamako.
- Kouressy, M., Bazile, D., Vaksman, M., Soumare, M., Doucoure, T. and Sidibe, A., 2003. La dynamique des agroecosystemes : un facteur explicatif de l'erosion varietale du sorgho, le cas de la zone Mali-Sud. In: P. Dugué and P. Jouve (Editors), Actes du colloque international, 25-27 février 2003, Organisation spatiale et gestion des ressources et des territoires ruraux., Montpellier, France. Umr Sagert, Cnearc.
- Kouressy, M., Traoré, S., Vaksman, M., Grum, M., Maikano, I., Soumaré, M., Traoré, P.S., Bazile, D., Dingkuhn, M. and Sidibé, A., 2008. Adaptation des sorghos du Mali à la variabilité climatique. *Cahiers Agricultures*, 17(2): 95-100.
- Kouyaté, Z., Franzluebbers, K., Juo, A.S. and Hossner, L.R., 2000. Tillage, crop residue, legume rotation, and green manure effects on sorghum and millet yields in the semiarid tropics of Mali. *Plant and Soil*, 225(1-2): 141-151.
- Kucharik, C.J. and Serbin, S.P., 2008. Impacts of recent climate change on Wisconsin corn and soybean yield trend. *Environment Research Letters*, 3: 10.
- Lançon, J., Wery, J., Rapidel, B., Angokaye, M., Gérardiaux, E., Gaborel, C., Ballo, D. and Fadegnon, B., 2007. An improved methodology for integrated crop management systems. *Agronomy for Sustainable development*, 27(2): 101-110.
- Laris, P. and Foltz, J., 2011. "Cotton as Catalyst: The Shifting Role of Fertilizer in Mali's Silent Maize Revolution". Mimeo, University of Wisconsin - Madison.
- Le Barbé, L., Lebel, T. and Tapsoba, D., 2002. Rainfall Variability in West Africa during the Years 1950-90. *Journal of Climate*, 15(2): 187-202.
- Leakey, A.D., Ainsworth, E.A., Bernacchi, C.J., Rogers, A., Long, S.P. and Ort, D.R., 2009. Elevated CO2 effects on plant carbon, nitrogen, and water relations: six important lessons from FACE. *Journal of Experimental Botany*, 60(10): 2859-2876.
- Lobell, D.B. and Burke, M.B., 2008. Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. *Environment Research Letters*, 3: 8.
- Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylor, R.L., 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science*, 319: 607-10.
- Lobell, D.B. and Field, C.B., 2007. Global scale climate-crop yield relationships and the impacts of recent warming. *Environmental Research Letters*, 2: 7.
- Lobell, D.B., Ortiz-Monasterio, J.I., Asner, G.P., Matson, P.A., Naylor, R.L. and Falcon, W.P., 2005. Analysis of wheat yield and climatic trends in Mexico. *Field Crops Research*, 94: 250-256.
- Lobell, D.B., Schlenker, W. and Costa-Roberts, J., 2011. Climate trends and global crop production since 1980. *Science*, 333(6042): 616-620.
- Luo, Y., Wan, S., Hui, D. and Wallace, L.L., 2001. Acclimatization of soil respiration to warming in a tall grass prairie. *nature*, 413(6856): 622-625.
- Lybbert, T.J. and Sumner, D.A., 2012. Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. *Food Policy*, 37(1): 114-123.

## References

- Mackill, D.J., Coffman, W. and L.J., R., 1982. Pollen shedding and combining ability for high temperature tolerance in rice. *Crop Science*, 20: 730-733.
- Mahalakshmi, V. and Bidinger, F.R., 1985. Water stress and time of floral initiation in pearl millet. *Journal of Agricultural Science*, 105: 437-445.
- Manu, A., Wilding, L., Hossner, L., Pfordresher, A. and Geiger, S., 1996. Soil parameters related to crop growth variability in Western Niger, West Africa. *Soil Science Society of America Journal*, 60(1): 283-288.
- Maracchi, G., Bacci, L., Cantini, C. and Haimanot, M.T., 1993. Effect of water deficit in vegetative and post-flowering phases on pearl millet grown in controller environment. *Agric. Med* 123: 65-71.
- McDowell, R.E., 1988. Importance of crop residues for feeding livestock in smallholder farming systems. In: J.D. Reed, B.S. Capper and P.J.H. Neate (Editors), *Plant breeding and the nutritive value of crop residues. Proceedings of a workshop held at ILCA, Addis Ababa, Ethiopia, 7-10 December 1987*. ILCA, Addis Ababa.
- McWilliams, D., 2003. Drought strategies for corn and grain sorghum. *Coop Ext. Circ. 580*, New Mexico State Univ., Las Cruces, NM.
- Milgroom, J. and Giller, K., 2013. Courting the rain: Rethinking seasonality and adaptation to recurrent drought in semi-arid southern Africa. *Agricultural Systems*, 118: 91-104.
- Mishra, A., Hansen, J.W., Dingkuhn, M., Baron, C., Traoré, S.B., Ndiaye, O. and Ward, M.N., 2008. Sorghum yield prediction from seasonal rainfall forecasts in Burkina Faso. *Agricultural and Forest Meteorology*, 148(11): 1798-1814.
- Mohino, E., Janicot, S. and Bader, J., 2011. Sahel rainfall and decadal to multi-decadal sea surface temperature variability. *Climate dynamics*, 37(3-4): 419-440.
- Mortimore, M.J. and Adams, W.M., 2001. Farmer adaptation, change and 'crisis' in the Sahel. *Global Environmental Change*, 11(1): 49-57.
- Muchow, R., Sinclair, T. and Bennett, J.M., 1990. Temperature and solar radiation effects on potential maize yield across locations. *Agronomy Journal*, 82(2): 338-343.
- Muller, C., 2011. *Agriculture: harvesting from uncertainties* Nature Climate Change, 1 253-4.
- Muller, C., Bondeau, A., Popp, A., Waha, K. and Fader, M., 2010. Climate change impacts on agricultural yields. Background note to the World Development Report 2010. Potsdam Institute for Climate Impact Research, Potsdam.
- Mutiso, S.K., 1997. Indigenous knowledge in drought and famine forecasting in Machakos District, Kenya. In: W.M. Adams and L.J. Slikkerveer (Editors), *Indigenous knowledge and change in African agriculture*. Ames IA: Center for Indigenous Knowledge for Agriculture and Rural Development, pp. 67-86.
- Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., Jung, T.Y. and Kram, T., 2000. Special report on emissions scenarios: a special report of Working Group III of the Intergovernmental Panel on Climate Change, Pacific Northwest National Laboratory, Richland, WA (US), Environmental Molecular Sciences Laboratory (US).
- Nelson, G.C., 2009. Climate change: Impact on agriculture and costs of adaptation. IFPRI.
- Nicholls, N., 1997. Increased Australian wheat yield due to recent climate trends. *nature*, 387: 484-485.
- Nicholson, S.E., 1980. The nature of rainfall fluctuations in subtropical West Africa. *Monthly Weather Review*, 108(4): 473-487.
- Nicholson, S.E., 2001. Climatic and environmental change in Africa during the last two centuries. *Climate Research*, 17(2): 123-144.
- Nicholson, S.E., Some, B. and Kone, B., 2000. An analysis of recent rainfall conditions in West Africa, including the rainy seasons of

## References

- the 1997 El Nino and the 1998 La Nina years'. *Journal of Climate*, 13: 2628-2640.
- Nubukpo, K. and Keita, M.S., 2006. Prix mondiaux, prix au producteur et avenir de la filière coton au Mali. *Cahiers Agricultures*, 15 35-41.
- Nyamangara, J., Gotosa, J. and Mpofu, S.E., 2001. Cattle manure effects on structural stability and water retention capacity of a granitic sandy soil in Zimbabwe. *Soil and Tillage Research*, 62: 157-162.
- Oladipo, E.O. and Kyari, J.D., 1993. Fluctuations in the onset, termination and length of the growing season in northern Nigeria *Theor. Appl. Climatol.*, 347: 241-50.
- OMA, 2012. Le reflet: Bulletin mensuel du marche agricole. Observatoire du Marche Agricole, Mai 2012.
- Omotosho, J.B., Balogun, A.A. and Ogunjobi, K., 2000. Predicting monthly and seasonal rainfall, onset and cessation of the rainy season in West Africa using only surface data. *International Journal of Climatology*, 20: 865-880.
- Ouattara, M., Vaksman, M., Reyniers, F.N., Kouressy, M. and Niangado, O., 1998. Variabilité phénologique des sorghos du Mali et adaptation à la diversité des agro-écosystèmes. In: L. Bacci and F.N. Reyniers (Editors), *Le futur des céréales photopériodiques pour une production durable en Afrique tropicale semi-aride.*, CeSIA, Florence, Italy, pp. 123-137.
- Ouédraogo, E., Mando, A. and Stroosnijder, L., 2006. Effects of tillage, organic resources and nitrogen fertiliser on soil carbon dynamics and crop nitrogen uptake in semi-arid West Africa. *Soil and Tillage Research*, 91(1): 57-67.
- Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, M. and Fischer, G., 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change*, 14(1): 53-67.
- Pedercini, M., Kanamaru, H. and Derwisch, S., 2012. Potential impacts of climate change on food security in Mali. *Natural Resources Management and Environment Department*, FAO, Rome.
- Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S. and Cassman, K.G., 2004. Rice yields decline with higher night temperature from global warming. *PNAS*, 101 ( 27): 9971-9975.
- Piani, C., Weedon, G., Best, M., Gomes, S., Viterbo, P., Hagemann, S. and Haerter, J., 2010. Statistical bias correction of global simulated daily precipitation and temperature for the application of hydrological models. *Journal of Hydrology*, 395(3): 199-215.
- Pieri, C., 1989. La fumure des céréales de culture sèche en République du Mali. *Première essai de synthèse. Agronomie Tropical*, 28: 751-766.
- Piéri, C., 1989. Fertilité des terres de savanes. *Bilan de trente ans de recherche et de développement agricoles au sud du Sahara.* (Ministère de la Coopération et du développement, CIRAD): 443 pp.
- Pope, V., Brown, S., Clark, R., Collins, M., Collins, W., Dearden, C., Gunson, J., Harris, G., Jones, C. and Keen, A., 2007. The Met Office Hadley Centre climate modelling capability: the competing requirements for improved resolution, complexity and dealing with uncertainty. *Philosophical Transactions of the Royal Society. Mathematical, Physical and Engineering Sciences*, 365(1860): 2635-2657.
- Powell, J.M., Pearson, R.A. and Hiernaux, P.H., 2004. Review and interpretation: Crop-livestock interactions in the West African drylands. *Agronomy Journal*, 96: 469-483.
- Rahman, H., 2006. Number and weight of cotton lint fibres: variation due to high temperatures in the field *Australian Journal of Agricultural Research*, 57: 83-590.



## References

- Raman, C.V.R., 1974. Analysis of commencement of Monsoon rains over Maharashtra State for agricultural planning. Scientific Report 216 Meteorological Department, Poona, India.
- Rapidel, B., Defèche, C., Traoré, B., Lançon, J. and Wery, J., 2006. In-field development of a conceptual crop functioning and management model: A case study on cotton in southern Mali. *European Journal of Agronomy*, 24: 304-315.
- Rapidel, B., Traoré, B.S., Sissoko, F., Lançon, J. and Wery, J., 2009. Experiment-based prototyping to design and assess cotton management systems in West Africa. *Agronomy for Sustainable development*, 29(4): 545-556.
- Reddy, K., Hodges, H. and Reddy, V., 1992. Temperature effects on cotton fruit retention. *Agronomy Journal*, 84(1): 26-30.
- Rietveld, A., 2009. Livelihood strategies in a globalizing world: Analysis of farmers' strategies in Southern Mali with emphasis on milk production. MSc Thesis Rural Sociology and Plant Production Systems. Wageningen University.
- Rockstrom, J., 1995. Biomass production in dry tropical zones: How to increase water productivity. In *Land and Water Integration and River Basin Management*. Land & Water Bulletin No. 1. pp 31-49. FAO, Rome, Italy.
- Roncoli, C., Ingram, K. and Kirshen, P., 2001. The costs and risks of coping with drought: livelihood impacts and farmers' responses in Burkina Faso. *Climate Research*, 19(2): 119-132.
- Rosegrant, M.W., Cai, X. and Cline, S.A., 2002. World Water and Food to 2025: Dealing with Scarcity. IFPRI-2020 Vision /International Water Management book, Washington, D.C. IFPRI.
- Rosenzweig, C. and Hillel, D., 1998. *Climate Change and the Global Harvest: Potential Impacts of the Greenhouse Effect on Agriculture*, Oxford University Press, New York.
- Rosenzweig, C., Jones, J.W., Hatfield, J.L., Ruane, A.C., Boote, K.J., Thorburn, P., Antle, J.M., Nelson, G.C., Porter, C., Janssen, S., Asseng, S., Basso, B., Ewert, F., Wallach, D., Baigorria, G. and Winter, J.M., 2013. The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. *Agricultural and Forest Meteorology*, 170: 166-182.
- Rosenzweig, C. and Parry, M.L., 1994. Potential impact of climate-change on world food supply. *nature*, 367: 133-138.
- Roudier, P., Sultan, B., Quirion, P. and Berg, A., 2011. The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, 21(3): 1073-1083.
- Rurinda, J., Mapfumo, P., van Wijk, M.T., Mtambanengwe, F., Rufino, M.C., Chikowo, R. and Giller, K.E., 2013. Managing soil fertility to adapt to rainfall variability in smallholder cropping systems in Zimbabwe. *Field Crops Research*, 154(0): 211-225.
- Saini, H.S., 1997. Effects of water stress on male gametophyte development in plants. *Sex Plant Reprod*, 10: 67-73.
- Salack, S. and Traore, S., 2006. Impacts des changements climatiques sur la production du mil et du sorgho dans les sites pilotes du plateau central, de Tahoua et de Fakara. Internship report. AGRHYMET/CILSS, Niamey, Niger.
- Sanogo, O.M., 2010. Participatory evaluation of the dairy cow supplementation technologies in a country setting at Mali (Koutiala)/ Évaluation participative des technologies de supplementation des vaches laitières en milieu paysan au Mali (Koutiala). *Canadian Journal of Development Studies*, 31(1-2): 91-106.
- Sawadogo-Kaboré, S., Fosu, M., Tabo, R., Kanton, R., Buah, S., Bationo, A., Ouédraogo, S., Pale, S., Bonzi, M. and Ouattara, K., 2009. Improving crop productivity and farmer income using fertilizer microdosing and the warrantage system in the Volta Basin. CGIAR Challenge Program on Water and Food: 135.



## References

---

- Schlenker, W. and Lobell, D.B., 2010. Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5(1): 014010.
- Segele, Z. and Lamb, P., 2005. Characterization and variability of Kiremt rainy season over Ethiopia. *Meteorology and Atmospheric Physics*, 89(1-4): 153-180.
- Sere, C. and Steinfeld, H., 1996. World Livestock Production Systems Current Status, Issues and Trends. Animal Production. and Health Paper, 127(FAO, Rome).
- Servat, E., Paturel, J.E., Kouame, B., Travaglio, M., Ouedraogo, M., Boyer, J.F., Lubes-Niel, H., Fristch, J.M., Masson, J.M. and Marieu, B., 1998. Identification, caractérisation et conséquences d'une variabilité hydrologique en Afrique de l'Ouest et Centrale. In: E. Servat, D. Hughes, J.M. Fritsch and M. Hulme (Editors), *Water Ressources Variability in Africa during the XXth Century*, Abidjan, pp. 323-337.
- Shaw, A.B., 1987. An analysis of the rainfall regimes on the coastal region of Guyana. *International Journal of Climatology*, 7: 291-302.
- Sheffield, J. and Wood, E.F., 2007. Characteristics of global and regional drought, 1950-2000: Analysis of soil moisture data from off-line simulation of the terrestrial hydrologic cycle. *Journal of Geophysical Research: Atmospheres* (1984-2012), 112(D17).
- Shi, Z., Zhang, S., Li, F., Wang, Z., Zhang, X., Zhang, Y. and Zhu, M., 2008. Comparison and analysis on maize yield performance of mid-maturing, mid-late maturing and late maturing varieties in Liaoning areas. *Journal of Maize Science*, 16(6): 6-10.
- Shinoda, M., Okatani, T. and Saloum, M., 1999. Diurnal variations of rainfall over Niger in the West African Sahel: A comparison between wet and drought years. *International Journal of Climatology*, 19(1): 81-94.
- Sidibé, A., Vellema, S., Dembelé, F., Traoré, M. and Kuyper, T.W., 2012. Innovation processes navigated by women groups in the Malian shea sector: How targeting of international niche markets results in fragmentation and obstructs co-ordination. *NJAS - Wageningen Journal of Life Sciences*, 60-63: 29-36.
- Sillitoe, P., 1998. The development of indigenous knowledge: A new applied anthropology 1. *Current anthropology*, 39(2): 223-252.
- Singh, B., El Maayar, M., André, P., Bryant, C. and Thouez, J.-P., 1998. Impacts of a Ghg-Induced Climate Change on Crop Yields: Effects of Acceleration in Maturation, Moisture Stress and Optimal Temperature. *Climatic Change*, 38(1): 51-86.
- Sissoko, F., Affholder, F., Autfray, P., Wery, J. and Rapidel, B., 2013. Wet years and farmers' practices may offset the benefits of residue retention on runoff and yield in cotton fields in the Sudan-Sahelian zone. *Agricultural Water Management*, 119(0): 89-99.
- Sisworo, W.H., Mitrosuhardjo, M., Rasjid, H. and Myers, R., 1990. The relative roles of N fixation, fertilizer, crop residues and soil in supplying N in multiple cropping systems in a humid, tropical upland cropping system. *Plant and Soil*, 121(1): 73-82.
- Sivakumar, M. and Hatfield, J., 1990. Spatial variability of rainfall at an experimental station in Niger, West Africa. *Theoretical and applied climatology*, 42(1): 33-39.
- Sivakumar, M.V., Konaté, M. and Virmani, S.M., 1984. *Agroclimatologie de l'Afrique de l'Ouest : le Mali.*, Bulletin d'Information. Patancheru, ICRISAT.
- Sivakumar, M.V.K., 1988. Predicting rainy season potential from the onset of rains in southern sahelian and sudanian climatic zones of West Africa. *Agricultural and Forest Meteorology*, 42: 295-305.
- Sivakumar, M.V.K., Das, H.P. and Brunini, O., 2005. Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics *Climatic Change*, 70: 31-72.

## References

- Soler, C.M.T., Maman, N., Zhang, X., Mason, S.C. and Hoogenboom, G., 2008. Determining optimum planting dates for pearl millet for two contrasting environments using a modelling approach. *Journal of Agricultural Science*, 146: 445-459.
- Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L (Eds), 2007. *Climate change: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York.
- Sombroek, W.G. and Gommers, R., 1997. L'énigme: Changement de climat - agriculture. In: FAO and POLYTECHNICA (Editors), *Changements du climat et production agricole. Agriculture mondiale: Horizon 2010*, Rome, pp. 472.
- Soumare, M., 2008. *Dynamique et durabilité des systèmes agricoles à base de coton au Mali*, Université de Paris X Nanterre UFR des Sciences sociales et d'administration. Thèse de doctorat en géographie humaine, économique et régionale.
- Soumaré, M., Bazile, D., Vaksman, M., Kouressy, M., Diallo, K. and Hamala Diakité, C.H., 2004. Diversité agroécosystémique et devenir des céréales traditionnelles au sud du Mali. *Cahiers Agricultures*, 17(2): 79-85.
- Staatz, J., Kelly, V., Boughton, D., Dembélé, N.N., Sohlberg, M., Berthé, A., Skidmore, M., Diarra, C.O., Murekezi, A., Richardson, R., Simpson, B., Perakis, S., Diallo, A.S., Adjao, R., Sako, M., Mensopé, N. and Coulibaly, J., 2011. *Malian agricultural sector assessment 2011*, USAID-Mali and Michigan State University.
- Stern, R.D. and Coe, R., 1982. The use of rainfall models in agricultural planning. *Agricultural Meteorology*, 26: 35-50.
- Stern, R.D. and Cooper, P.J.M., 2011. Assessing climate risk and climate change using rainfall data- A case study from Zambia. *Experimental Agriculture*, 47: 241-266.
- Stern, R.D., Dennett, M.D. and Dale, I.C., 1981. Analysing daily rainfall measurements to give agronomically useful results. I. Direct Methods. *Experimental Agriculture*, 18: 223-236.
- Stewart, J.I., 1991. Principles and performance of response farming. In: R.C. Muchow and J.A. Bellamy (Editors), *Proceedings of the international symposium on Climatic risk in crop production: Models and management for the semiarid tropics and subtropics*, Brisbane, Australia, pp. 361-382.
- Stoop, W.A., Pattanayak, C.M., Matlon, P.J. and Root, W.R., 1981. A strategy to raise the productivity of subsistence farming systems in the West African semi-arid tropics. *Proceedings Sorghum in the Eighties*, ICRISAT, Patancheru, India (1981), pp 519-526.
- Stott, P.A., Jones, G.S., Christidis, N., Zwiers, F.W., Hegerl, G. and Shiogama, H., 2011. Single-step attribution of increasing frequencies of very warm regional temperatures to human influence. *Atmospheric Science Letters*, 12(2): 220-227.
- Stott, P.A., Stone, D.A. and Allen, M.R., 2004. Human contribution to the European heatwave of 2003. *Nature*, 432(7017): 610-614.
- Sultan, B., Baron, C., Dingkuhn, M., Sarr, B. and Janicot, S., 2005. Agricultural impacts of large-scale variability of the West African monsoon. *Agricultural and Forest Meteorology*, 128(1-2): 93-110.
- Sultan, B. and Janicot, S., 2003. The West African monsoon dynamics. Part II: The "preonset" and "onset" of the summer monsoon. *Journal of Climate*, 16: 3407-3427.
- Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., Dingkuhn, M., Ciais, P., Guimberteau, M., Traore, S. and Baron, C., 2013. Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. *Environmental Research Letters*, 8(1): 014040.

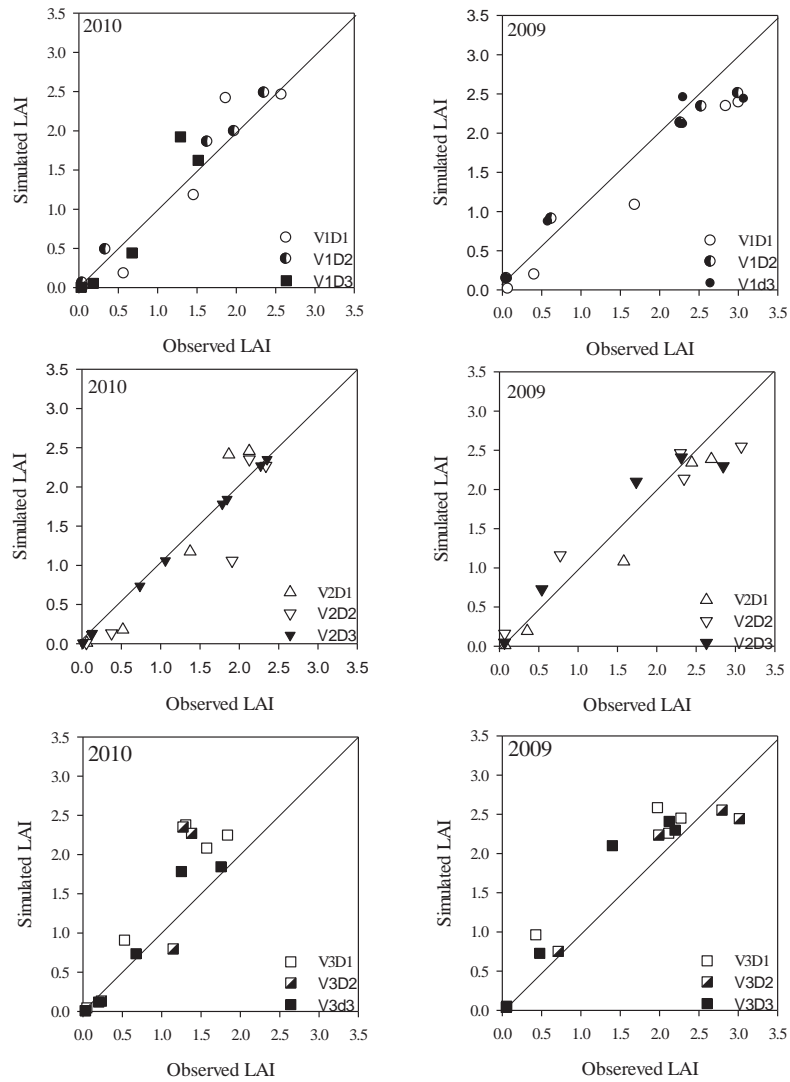
## References

- Tabo, R., Bationo, A., Gerard, B., Ndjeunga, J., Marchal, D., Amadou, B., Annou, M.G., Sogodogo, D., Taonda, J.-B.S. and Hassane, O., 2007. Improving cereal productivity and farmers' income using a strategic application of fertilizers in West Africa, *Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities*. Springer, pp. 201-208.
- Tanaka, A. and Hara, T., 1974. Study on the nutritio-physiology of maize plant. 10. Grain yield as affected by sowing date *Field Crop Abstr.*, 27: 555.
- Taylor, K.E., Stouffer, R.J. and Meehl, G.A., 2012. An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, 93(4): 485-498.
- Thomas, D.G., Twyman, C., Osbahr, H. and Hewitson, B., 2007. Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change*, 83(3): 301-322.
- Tingem, M. and Rivington, M., 2009. Adaptation for crop agriculture to climate change in Cameroon: Turning on the heat. *Mitigation and Adaptation Strategies for Global Change*, 14(2): 153-168.
- Traore, B., 2007. Utilisation d'un modèle de simulation du fonctionnement de l'exploitation agricole comme interface de dialogue entre la recherche agronomique et les agriculteurs concernant l'adoption de nouvelles options techniques de culture. Master en Agronomie et Agroalimentaire, Option: Agronomie et Systèmes de Culture Intégrés en Zone Tropicale Thesis, SupAgro, 34 pp.
- Traore, B., 2011. Fiche technique de la culture du coton à forte densité et à croissance régulée au Mali, Programme Coton, IER, Bamako -Mali.
- Traore, B., Corbeels, M., van Wijk, M.T., Rufino, M.C. and Giller, K.E., 2013. Effects of climate variability and climate change on crop production in southern Mali. *European Journal of Agronomy*, 49: 115-125.
- Traore, B., Rapidel, B., Sissoko, F. and Doucouré, C.T., 2005. Evolution des techniques culturales en zone cotonnière entre 1997 et 2002. *Les Cahiers de l'Economie Rurale*, 2: 21-28.
- Traore, B., van Wijk, M.T., Descheemaeker, K., Corbeels, M., Rufino, M.C. and Giller, K.E., 2014. Evaluation of climate adaptation options for Sudano-Sahelian cropping systems. *Field Crops Research*, 156: 63-75.
- Traore, P.C.S., Kouressy, M., Vaksmann, M., Tabo, R., Maikano, I., Traoré, S.B. and Cooper, P., 2007. Climate prediction and agriculture: What Is different about Sudano-Sahelian West Africa? chapter 19. In: M.V.K. Sivakumar and J. Hansen (Editors), *Climate Prediction and Agriculture: Advances and Challenges*. Springer, USA, pp. 189-203.
- Traoré, S.B., Reyniers, F.N., Vaksmann, M., Koné, B., Sidibé, A., Yoroté, A., Yattara, K. and M., K., 2000. Adaptation à la sécheresse des écotypes locaux de sécheresse. *Sécheresse*, 11: 227-37.
- Trenberth, K.E., 2011. Changes in precipitation with climate change. *Climate Research*, 47(1): 123.
- Vadez, V., Hash, T., Biding, F.R. and Kholova, J., 2012. II.1.5 Phenotyping pearl millet for adaptation to drought. *Frontiers in Physiology*, 3
- Vaksmann, M., Kouressy, M., Chantereau, J., Bazile, D., Sagnard, F., Touré, A., Sanogo, O., Diawara, G. and Danté, A., 2008. Utilisation de la diversité génétique des sorghos locaux du Mali. *Cahiers Agricultures*, 17(2): 140-145.
- Vaksmann, M., Traoré, S.B. and Niangado, O., 1996. Le photopériodisme des sorghos africains [Photoperiodism of African sorghums]. *Agriculture et Développement*, 9: 13-18.
- Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woerner, P.L. and Sangina, N., 2010. Integrated soil fertility management. Operational definition and consequences for

## References

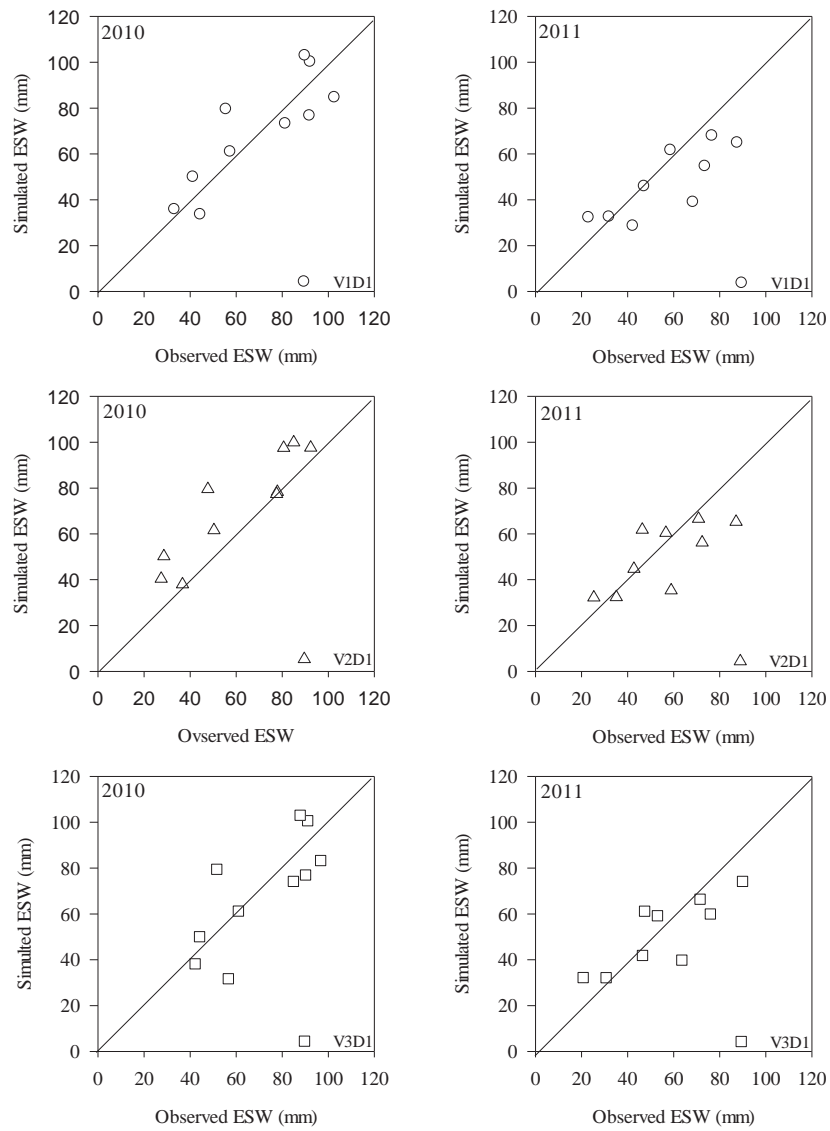
- implementation and dissemination. *Outlook on Agriculture*, 39(1): 17-24.
- Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R. and Six, J., 2011. Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil*, 339(1): 35-50.
- Vedwan, N., 2006. Culture, climate and the environment: local knowledge and perception of climate change among apple growers in Northwestern India. *Journal of Ecological Anthropology*, 10(1): 4-18.
- Veldkamp, W.J., Traore, A., N'Diaye, M.K., Keita, M.K., Keita, B. and Bagayoko, M., 1991. Fertilité des sols du Mali. Mali-Sud / Office du Niger. Interpretation analytiques des données des sols et des Plantes. Bamako, Mali, Institut d'Economie Rurale, Laboratoire Sol-Eau-Plante. 149 Pages.
- Voortman, R.L., Brouwer, J. and Albersen, P.J., 2004. Characterization of spatial soil variability and its effect on Millet yield on Sudano-Sahelian coversands in SW Niger. *Geoderma*, 121(1-2): 65-82.
- Waha, K., Müller, C., Bondeau, A., Dietrich, J.P., Kurukulasuriya, P., Heinke, J. and Lotze-Campen, H., 2013a. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change*, 23(1): 130-143.
- Waha, K., Muller, C. and Rolinski, S., 2013b. Separate and combined effects of temperature and precipitation change on maize yields in sub-Saharan Africa for mid-to late-21st century. *Global and Planetary Change*.
- Washington, R. and Harrison, M., 2004. African Climate Report: A report commissioned by the UK Government to review African climate science, policy and options for action, Climatology Research Group, Oxford University Centre for the Environment, UK.
- Washington, R. and Preston, A., 2006. Extreme wet years over southern Africa: Role of Indian Ocean sea surface temperatures. *Journal of Geophysical Research: Atmospheres* (1984-2012), 111(D15).
- WCRP, 1999. Climate Research for Africa, Informal Report No. 16/1999, World Climate Research Programme, International Clivar Project Office Publication Series No. 29, Southampton, United Kingdom.
- Weber, G., Elemo, K., Lagoke, S.T.O., Awad, A. and Oikeh, S., 1995. Population dynamics and determinants of *Striga hermonthica* on maize and sorghum in savanna farming systems. *Crop Protection*, 14(4): 283-290.
- Weedon, G., Gomes, S., Viterbo, P., Shuttleworth, W., Blyth, E., Österle, H., Adam, J., Bellouin, N., Boucher, O. and Best, M., 2011. Creation of the WATCH Forcing Data and its use to assess global and regional reference crop evaporation over land during the twentieth century. *Journal of Hydrometeorology*, 12(5): 823-848.
- White, J.W., Hoogenboom, G., Kimball, B.A. and Wall, G.W., 2011. Methodologies for simulating impacts of climate change on crop production. *Field Crops Research*, 124(3): 357-368.
- Willmott, C.J., Ackleson, S.G., Davis, R.E., Feddema, J.J., Klink, K.M., Legates, D.R., O'Donnell, J. and Rowe, C.M., 1985. Statistics for the evaluation and comparison of models. *Journal of Geophysical Research: Oceans* (1978-2012), 90(C5): 8995-9005.
- World Bank, 2008. World Development Report 2008 - Agriculture for Development. World Bank, Washington D.C.
- Yattara, A.A. and Sissoko, S., 2007. Fiche technique des variétés de coton cultivées au Mali. Communication de l'IER, Bamako, Mali: 5 pp.
- Zeng, N., 2003. Drought in the Sahel. *Science*, 302: 999-1000.
- Zheng, K.L. and Mackill, D.T., 1982. Effect of high temperature on anther dehiscence and pollination in rice. *Sabarao J*, 14: 61-66.
- Zida, Z., 2011. Long-term effects of conservation soil management in Saria, Burkina Faso, West Africa. Wageningen University and Research Centre.

Appendix 1: APSIM simulation of leaf area index



## Appendices

### Appendix 2: APSIM simulation of Extractive soil water



Appendix 3: code used in Genstat for Statics analysis

```
RESTRICT Yield ; Crop.ni. 'cotton'
BLOCK Bloc/main_plot/plot/subplot
matrix [row= !t('maize-millet', 'maize-sorghum', 'millet-sorghum');col=4;\
        val=0,1,-1,0, 0,1,0,-1, 0,0,1,-1] contr
TREATMENTS year*comp(Crop;3;contr)*variety*date
COVARIATE "No Covariate"
ANOVA [PRINT=aovtable,information,means; FACT=32; CONTRASTS=7;
PCONTRASTS=7; \
        FPROB=yes; PSE=diff] Yield ; RES=res ; FIT=fit
GRAPH [NRO=25 ; NCOL=65] res ; fit
RESTRICT Yield
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## Appendices

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### Summary

In the Sudano-Sahelian zone of West Africa (SSWA) agricultural production remains the main source of livelihood for rural communities, providing employment to more than 60 percent of the population and contributing to about 30% of gross domestic product. Smallholder agricultural production is dominated by rain-fed production of millet, sorghum and maize for food consumption and of cotton for the market. Farmers experience low yields and variable yields resulting in increasing uncertainty about the ability to produce the food needed for their families. Major factors contributing to such uncertainty and low productivity are climate variability, poor soil fertility, poor agricultural management and climate change. The objective of this thesis was to evaluate through experimentation, modelling and participatory approaches the real and perceived characteristics of climate variability and change and their effects on crop production in order to identify opportunities for enhancing the adaptive capacity of farmers in the Sudano - Sahelian zone.

The general approach was based on, first, understanding the past trend of climate and its effect on the yield of main crops cultivated in southern Mali; second, evaluating together with farmers different adaptation options in the field; third, evaluating climate adaptation options through experimentation on station; and fourth, evaluating the consequences of different adaptation options under different long term scenarios of climate change.

Effects of past climate variability and change on crop production in southern Mali were quantified by analysing long-term time series of weather data recorded in southern Mali, use of crop yield data from an experiment at the research station of the Institut de l'Economie Rurale de N'Tarla and from farmers' fields in ten districts in southern Mali. Minimum daily air temperature increased on average by 0.05°C per year during the period from 1965 to 2005 while maximum daily air temperature remained constant. Seasonal rainfall showed large inter-annual variability with no significant change over the 1965 – 2005 period. However, the total number of dry days within the growing season increased significantly at N'Tarla, indicating a change in rainfall distribution. Yields of cotton, sorghum and groundnut at the N'Tarla experiment varied (30%) without any clear trend over the years. There was a negative effect of maximum temperature, number of dry days and total seasonal rainfall on cotton yield. The variation in cotton yields was related to the rainfall distribution within the rainy season, with dry spells and seasonal dry days being key determinants of crop yield. In the driest districts, maize yields were positively correlated with rainfall. Our study shows that

cotton production in southern Mali would be affected by climate change, in particular through changes in the rainfall distribution.

A study on farmer's perceptions of climate change and variability and agricultural adaptation option in southern Mali was conducted in the village of Try and N'Goukan in 2010 and 2011. This study aimed to understand farmers' perceptions and to evaluate adaptation options together with farmers, including tactical management of planting date and use of mineral fertilizer. Farmers perceived an increase in annual rainfall variability, an increase in the occurrence of dry spells during the rainy season, and an increase in temperature. Overall, this is in line with the observed meteorological data, except for the perceived decrease in rainfall during the growing season, which was not observed. Drought tolerant, short maturing crop varieties and appropriate planting dates were the commonly preferred adaptation strategies to deal with climate variability. Use of chemical fertilizer enhances the yield and profitability of maize while the cost of fertilizer prohibits making profit with fertilizer use on millet. Training of farmers on important aspects of weather and its variability, and especially on the onset of the rains, is critical to enhancing adaptive capacity to climate change.

A field experiment was carried out during three consecutive growing seasons (from 2009 to 2011) at the agricultural research station of N'Tarla to evaluate climate adaptation options for Sudano-Sahelian cropping systems. Four major crops (maize, millet, sorghum and cotton) were included in the experiment. For each crop, three planting dates (early, medium, and late) and three varieties of long, medium, and short duration were compared. For fertilized cereal crops, maize out yielded millet and sorghum by respectively 57% and 45% across the three seasons. Analysis of 40 years of weather data indicated that this finding holds for longer time periods than the length of this trial. Late planting resulted in significant yield decreases for maize, sorghum and cotton, but not for millet. However, a short duration variety of millet was better adapted for late planting. When the rainy season starts late, sorghum planting can be delayed from the beginning of June to early July without substantial reductions in grain yield. Cotton yield at early planting was 28% larger than yield at medium planting and late planting gave the lowest yield with all three varieties. For all four crops the largest stover yields were obtained with early planting and the longer planting was delayed, the less stover was produced. There was an interaction between planting date and variety for millet and sorghum, while for maize and cotton the best planting date was more affected by the weather conditions. The findings of this study can support simple adaptation decisions: priority should

be given to planting cotton early; maize is the best option if fertilizer is available; planting of maize and sorghum can be delayed by up to a month without strong yield penalties; and millet should be planted last.

Long-term time series of future climate for the Sudano-Sahelian zone of Mali were coupled with the Agricultural Production Systems sIMulator (APSIM) model to analyse impacts of future climate change on cereal production and to evaluate potential adaptation options of crop management. We analysed changes in future rainfall, maximum and minimum temperature under two climatic scenarios leading to a radiative forcing of  $4.5 \text{ Wm}^{-2}$  and  $8.5 \text{ Wm}^{-2}$ . The main findings indicated that the temperature will increase over time. Generally stronger increases occur in the rcp8.5 scenario compared to the rcp4.5 scenario. The total annual rainfall is unlikely to change. By mid-century predicted maize grain yield losses were 45% and 47% with farmer's practice in the rcp4.5 and rcp8.5 scenarios respectively. The recommended fertilizer application did not offset the climate change impact but reduced the yield losses to 38% of the baseline yield with farmer's practice. For millet median yield loss was 16% and 14% with farmer's practice in the rcp4.5 and rcp8.5 scenario. If the recommended fertilizer rates are applied, the predicted yield losses with farmer's practice due to climate change are reversed in both climate scenarios. Coping with climate change appears to be possible. If current crop management is improved by avoiding delays in planting, application of recommended fertilization rates and use of best performing crop varieties yield losses due to climate change can be compensated and even turned into a yield increase compared with current yields.

Finally in general discussion I synthesised the main findings and draw some important conclusions in the context of smallholder farming system in the Sudano - Sahelian zone of West Africa. Our results showed that, under current conditions, the energy requirements of the households were satisfied by on-farm production for the large farm type while the medium and small farm type did not achieve food self-sufficiency.

Under future climate change, food availability will be reduced for all the farm types, but the large farm will still achieve food self – sufficiency in terms of energy requirement. The medium and small farm types see a further decrease in food self-sufficiency.

Addressing smallholder food self-sufficiency depends upon the capacity of each farm type to appropriately choose the planting date while taking into account the acceptable planting date window for each individual crop. Effectiveness of planting date as an adaptation option varies

## Summary

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according to farm type. Early planting is an important option to meet food self-sufficiency for the medium and small farm type. Strategies to cope with future climate are sustainable only when they are based on a sustainable production system incorporating appropriate soil fertility management.

### **Samenvatting**

Landbouw productie blijft de belangrijkste bron van inkomsten voor rurale gemeenschappen in de Sudan-Sahel zone van West Africa (SSWA) door banen te verschaffen voor meer dan 60 procent van de bevolking en door een bijdrage van ongeveer 30% aan het bruto nationaal product. Kleinschalige agrarische productie wordt gedomineerd door regenval afhankelijke productie van gierst, sorghum en mais voor voedselconsumptie en van katoen voor verkoop op de markt. Boeren hebben te maken met lage opbrengsten die leiden tot toenemende onzekerheid over hoe ze voldoende voedsel kunnen produceren om hun families te voeden. De belangrijkste factoren die deze lage productie en de daaruit volgende onzekerheid bepalen zijn de variabiliteit in het weer, een lage bodemvruchtbaarheid, slecht agrarisch beheer en klimaatsverandering. De doelstelling van deze thesis was om door experimenteel werk, modellering en participatieve methoden de echte variabiliteit, en veranderingen hierin, van het weer te contrasteren met wat de boeren denken dat deze variabiliteit is en denken wat er aan het veranderen is en de consequenties van deze variabiliteit en veranderingen daarin op gewasproductie te evalueren. Dit alles om mogelijkheden te identificeren om de aanpassingsmogelijkheden van boeren in de Sudan-Sahel zone te verbeteren. De algemene aanpak was om ten eerste, de klimaat trend en haar gevolgen voor de productie van de belangrijkste gewassen van zuid Mali in de afgelopen 40 jaar te analyseren; ten tweede om samen met boeren verschillende aanpassingsmogelijkheden in het veld te evalueren; ten derde om klimaatsaanpassingen te evalueren door middel van experimenten op een veldstation; en ten vierde om de lange termijn consequenties van verschillende aanpassingsmogelijkheden te evalueren onder verschillende scenarios van klimaatsverandering.

Effecten van variabiliteit in het weer in de afgelopen 40 jaar op gewasproductie in Mali werden gekwantificeerd door het analyseren van lange termijn datasets van het weer in zuid Mali, het gebruik van gewasopbrengst data van een experiment uitgevoerd op het onderzoeksstation van het Institut de l'Economie Rurale te N'Tarla en op boerenvelden in zuid Mali. De minimum dagtemperatuur nam gemiddeld met 0.05°C per jaar toe gedurende de periode van 1965 tot 2005, terwijl de maximum dagtemperatuur constant bleef. De regenval per seizoen liet een grote jaarlijkse variabiliteit zien, met geen significant verandering over de periode van 1965 tot 2005. Het totaal aantal droge dagen gedurende het groeiseizoen nam significant toe in N'Tarla, wat een verandering aangeeft in de regenval distributie. De opbrengsten van katoen, sorghum en pinda in het N'Tarla experiment varieerden sterk van

jaar tot jaar, zonder een trend te laten zien in de tijd. Er was een negatief effect van maximum temperatuur, het aantal droge dagen en de totale hoeveelheid regenval per seizoen op de katoenopbrengst. De variatie in katoenopbrengsten was gerelateerd aan de regenval distributie binnen een seizoen, waarbij droogteperiodes en het aantal droge dagen de bepalende factoren waren voor de gewasopbrengst. In de droogste gebieden waren de mais opbrengsten positief gecorreleerd aan regenval. Onze studie liet zien dat katoen productie in zuid Mali beïnvloed wordt door klimaatsverandering, en dan met name door veranderingen in de regenval distributie.

Een studie naar de door boeren geobserveerde klimaatsverandering en klimaatsvariabiliteit en de agrarische adaptatie-opties in zuid Mali werd uitgevoerd in de dopren Try en N’Goukan in 2010 en 2011. Deze studie beoogde om de meningen van boeren over klimaatsverandering en ariabiliteit te begrijpen en om samen met hen adaptatie-opties te evalueren, waaronder de keuze van plant datum en het gebruik van kunstmest. Boeren vertelden dat er een toename is in regenval variabiliteit, een toename in het aantal droogteperiodes gedurende het groeiseizoen, en een toename in temperatuur. Over het algemeen is dit in overeenkomst met de geobserveerde meteorologische data, behalve voor de afname in regenval tijdens het groeiseizoen die de boeren dachten waar te nemen, welke niet aanwezig was in de data. Droogte tolerante en snel rijpende crop variëteiten waren de meest geprefereerde adaptatie opties om met klimaatsvariabiliteit om te gaan. Gebruik van kunstmest laat de opbrengst en het financieel gewin van mais toenemen, terwijl voor gierst kunstmest te duur is om er winst mee te maken. Cursussen voor boeren over de belangrijke aspecten van weer and zijn variabiliteit, vooral bij het begin van het regenseizoen, is van kritisch belang om de capaciteit voor adaptatie aan klimaatsverandering van boeren te verbeteren.

Een veld experiment werd gedurende drie opeenvolgende groeiseizoenen (van 2009 tot 2011) uitgevoerd op het agrarische onderzoeksstation te N’Tarla om klimaats adaptatie opties te evalueren voor Sudan-Sahel gebaseerde gewas-systemen. Ik evalueerde de effecten van plant datum op de opbrengsten van verschillende variëteiten van 4 belangrijke gewassen (mais, gierst, sorghum en katoen). Drie plant data (vroeg, gemiddeld en laat) en drie variëteiten (lang, gemiddeld of kort rijpend) van elk gewas werden vergeleken. Bij de bemeste graangewassen was de opbrengst van mais 57% en 45% hoger dan die van gierst en sorghum. Analyse van 40 jaar weersgegevens liet zien dat deze bevindingen ook van toepassing zijn op langere periodes dan alleen de drie jaren van het experiment. Een late plant datum

resulteerde in significante gewas opbrengst verliezen voor mais, sorghum en katoen, maar niet voor gierst. Een kort rijpende variëteit van gierst liet echter zien het best aangepast te zijn aan een late plant datum. Als het regenseizoen laat start kan het planten van sorghum uitgesteld worden van begin van juni tot begin van juli zonder substantieel verlies in graan opbrengst. De katoen opbrengst bij een vroege plant datum was 28% hoger dan de opbrengst bij een gemiddelde plant datum, en een late plant datum gaf de laagste opbrengst voor alle drie de geteste variëteiten. Voor alle 4 de gewassen werden de hoogste gewasrest opbrengsten behaald bij een vroege plant datum, en hoe langer het planten werd uitgesteld hoe lager de gewasrest opbrengst was. Er was een interactie tussen plant datum en variëteit bij gierst en sorghum, terwijl bij mais en katoen de beste plant datum meer door de weersomstandigheden werd beïnvloed. De uitkomsten van deze studie kunnen eenvoudige adaptatie beslissingen ondersteunen: prioriteit zou gegeven moeten worden aan het zo vroeg mogelijk planten van katoen; mais is de best optie als kunstmest beschikbaar is; het planten van mais en sorghum kan met een maand uitgesteld worden zonder sterke opbrengstverliezen; en gierst zou als laatste geplant moeten worden.

Een lange termijn tijd serie voor het toekomstige klimaat van de Sudan-Sahel zone van Mali werd gekoppeld aan de Agricultural Production Systems sIMulator (APSIM) model om de impact van de toekomstige klimaatsverandering op graan productie te analyseren. We analyseerden veranderingen in de toekomstige regenval, maximum en minimum temperatuur onder twee klimaatsscenario's die leiden tot een radiative forcing van  $4.5 \text{ Wm}^{-2}$  and  $8.5 \text{ Wm}^{-2}$ ; quantificeerden het effect van klimaatsverandering op de opbrengsten van mais en gierst, en evalueerden potentiële adaptatie opties voor gewas management. De belangrijkste bevindingen lieten zien dat de temperatuur zal toenemen met de tijd. Een sterkere toename wordt voorspeld onder het rcp 8.5 scenario dan onder het rcp 4.5 scenario. De totale hoeveelheid regenval zal niet veranderen. De voorspelde graan opbrengst verliezen waren halverwege de eeuw 45% en 47% onder het huidige boeren management voor rcp 4.5 en rcp 8.5 respectievelijk. De aanbevolen kunstmest gift kon dit verlies niet volledige compenseren, maar reduceerde het verlies wel tot 38%. Voor gierst waren de mediane gewasopbrengst verliezen 14% en 16% onder het huidige boeren management in de rcp 4.5 en 8.5 scenario's. Als de aanbevolen hoeveelheid kunstmest werd toegepast, werd het verlies omgezet in een toename van de opbrengst in beide klimaatsscenario's. Omgaan met klimaatsverandering lijkt mogelijk. Als het huidige gewas management wordt verbeterd door vertraging in planten te vermijden, door het toepassen van de aanbevolen hoeveelheid kunstmest and het gebruik van

## Samenvatting

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de best presterende gewasvariëteiten kunnen de voorspelde verliezen in opbrengsten door klimaatsverandering gecompenseerd worden, en zelfs omgezet worden in een opbrengsttoename vergeleken met de huidige opbrengst niveaus.

In de algemene discussie maak ik een synthese van de belangrijkste bevindingen van mijn onderzoek en trek ik een aantal belangrijke conclusies in de context van kleine boerenbedrijven in de Sudan-Sahel zone van West Afrika. Onze resultaten lieten zien dat onder de huidige omstandigheden, de benodigde voedselenergie van huishoudens wordt bereikt met de productie van relatief grotere bedrijven, maar dat de gemiddelde en kleine bedrijfstypen niet voedsel zelfvoorzienend zijn. Onder toekomstige klimaatsverandering zal voedselbeschikbaarheid afnemen voor alle bedrijfstypen, maar de relatief grootste bedrijven zullen nog steeds zelf voorzienend zijn in termen van energie. De aanpak van de voedsel zelfvoorziening van kleine boerenbedrijven hangt af van de capaciteit van elk bedrijfstype om de juiste plant datum te kiezen op basis van de acceptabele plant datum ruimte voor elk gewas. De effectiviteit van plant datum als een adaptatie optie verschilt van bedrijf tot bedrijf. Vroeg planten is een belangrijke optie om voedsel zelfvoorzienend te worden voor de gemiddelde en kleine bedrijfstypen. Een strategie om om te gaan met het toekomstige klimaat kan alleen over een langere tijd succesvol zijn wanneer het gebaseerd is op een duurzaam productie-systeem het juiste management van de bodemvruchtbaarheid.



### Résumé

En zone Soudano - Sahélienne l'agriculture est la principale source de revenu pour les communautés rurales. Elle emploie plus de 60% de la population totale et contribue à hauteur de 30% au Produit Intérieur Brut. Cette agriculture est basée sur des cultures pluviales : sorgho, maïs et mil pour la nourriture humaine, et coton comme culture de rente. Ainsi ce type d'agriculture est fortement dépendant des conditions climatiques locales, en particulier de la pluviométrie, mais aussi du niveau de fertilité des sols et des pratiques culturales. La sécurité alimentaire des familles peut donc être remise en cause par des pratiques culturales inappropriées, des sols dégradés et des variations climatiques à court (variabilité climatique) et à long (changements climatiques) termes. L'objectif de cette thèse est d'identifier les options d'amélioration de la capacité d'adaptation des agriculteurs en zone Sudano – Sahélienne via la caractérisation de la variabilité et changement climatique, et de leurs effets sur les productions agricoles.

Notre approche générale est basée sur l'analyse de l'évolution du climat au cours des trente dernières années et de son impact sur les rendements des principales cultures pluviales au sud du Mali, l'identification et l'évaluation des différentes options d'adaptation à la variabilité et aux changements climatiques à l'aide de parcelles expérimentales, et l'évaluation des options d'adaptation en fonction de scénarios de changements climatiques via l'utilisation des outils de la modélisation.

Les effets de la variabilité et des changements climatiques sur la production agricole au cours des trois dernières décennies ont été quantifiés par l'analyse de longues séries de données météorologiques mises en relation avec des suivis de rendements agricoles de l'essai organo-minéral de la Station de Recherche Agronomique de N'Tarla. Il en résulte que la température minimale quotidienne de l'air a augmenté en moyenne de 0.05°C par an au cours de la période 1965-2005, tandis que la température maximale quotidienne de l'air est restée constante pendant cette même période. Les pluies saisonnières ont montré une grande variabilité interannuelle mais sans changement significatif du cumul annuel des précipitations au cours de la période 1965-2005. Le nombre total de jours sans pluie durant la période de culture a augmenté de manière significative, indiquant ainsi un changement dans la distribution de la pluie. Les rendements de coton, de sorgho et d'arachide ont présenté une grande variabilité (30 %), mais sans tendance claire de la baisse durant 1965-2005. Cependant des effets négatifs (significatifs) de la température maximale, du nombre de jours sans pluie et de la pluviométrie annuelle sur le rendement du coton ont été démontrés.

La variation des rendements de coton est liée à la distribution des précipitations et en particulier aux périodes de sécheresse intra-annuelle (intervalle sans pluies). Dans les zones à faible pluviométrie, les rendements de maïs sont positivement corrélés à la fréquence des pluies. L'étude montre que la production de coton dans le sud du Mali est affectée par le changement climatique, en particulier par des modifications dans la distribution des pluies.

En 2010 et 2011, une étude a été menée au Mali (Try et N'Goukan) pour comprendre la perception des agriculteurs sur la variabilité et les changements climatiques, et pour évaluer des options d'adaptation à ces changements climatiques. Ces options sont basées sur l'amélioration de la gestion tactique des dates de semis et de l'utilisation des engrais minéraux. Il en résulte que les agriculteurs ont perçu une augmentation de la variation interannuelle des précipitations, une augmentation de la fréquence des intervalles de sécheresse au cours la saison des pluies, et une augmentation de la température moyenne. Dans l'ensemble, ces perceptions des agriculteurs sont conformes aux observations météorologiques. Pour faire face à la variabilité climatique, les stratégies d'adaptation envisagées par les agriculteurs portent sur l'utilisation des variétés tolérantes à la sécheresse, des variétés à cycle court et le choix de dates de semis appropriées. Nos essais expérimentaux avec les agriculteurs montrent que l'utilisation de l'engrais chimique améliore les rendements de maïs et de mil. Cependant elle ne semble rentable que pour la culture de maïs bien que le rendement de mil soit significativement augmenté. Enfin, pour améliorer les capacités d'adaptation des agriculteurs, il serait souhaitable de les sensibiliser sur les principales caractéristiques du climat et de sa variabilité, et surtout sur la gestion du calendrier cultural au début de la saison des pluies.

Afin d'évaluer les options techniques d'adaptation à la variabilité climatique, un essai expérimental a été réalisé de 2009 à 2011 (Station de Recherche Agricole de N'Tarla). L'effet des dates de semis (précoce, moyenne et tardive) sur le rendement de trois variétés (cycle long, moyen et court) des quatre principales cultures pluviales (maïs, mil, sorgho et coton) ont été évalués. Les résultats montrent que le rendement moyen du maïs obtenu au cours des trois saisons agricoles est supérieur de 57% et 45% à celui du mil et du sorgho, respectivement. L'analyse des données météorologiques sur les quatre dernières décennies confirme que ce résultat peut être valable sur une période aussi longue que celle la durée de l'étude. Bien que le semis tardif ait occasionné une baisse significative des rendements de maïs, de sorgho et de coton, ceci n'a pas été observé pour les rendements de mil. La variété à cycle court de mil semble donc mieux adaptée pour les semis tardifs. Lorsque la saison des pluies commence tardivement, le semis de sorgho peut être retardé de début Juin à début Juillet sans réductions

significatives du rendement. Le rendement de coton avec la date de semis précoce était 28% supérieur au rendement obtenu avec la date de semis moyenne. Pour les trois variétés (cycle long, moyen et court), le plus faible rendement a été obtenu avec le semis tardif. Les dates de semis en interaction avec les variétés ont un effet significatif sur les rendements de mil et de sorgho. Pour les rendements de maïs et de coton, la meilleure date de semis a été plus affectée par les conditions météorologiques. Les résultats de cette étude constituent une contribution majeure aux pratiques d'adaptation à la variabilité climatique. La priorité doit être accordée au semis du coton en début de la saison des pluies; le maïs est la meilleure option si l'engrais minéral est disponible; les semis du maïs et du sorgho peuvent être retardés jusqu'en début juillet sans une répercussion majeure sur le rendement et le mil doit être planté en dernier.

Afin d'analyser l'impact des changements du futur climat sur les systèmes de production du maïs et du mil, nous avons utilisé des projections climatiques (2040-2069) pour la zone Soudano Sahélienne du Mali. Ces informations ont été ensuite couplées au modèle de culture APSIM (Simulateur des Systèmes de Production Agricole). Pour les cinquante prochaines années, nous avons analysé les changements de la pluviométrie, la température maximale et minimale et avons testé deux scénarios climatiques correspondant à une force radiative de  $4,5 \text{ Wm}^{-2}$  (scénario rcp4.5) et  $8,5 \text{ Wm}^{-2}$  (scénario rcp8.5); nous avons ensuite évalué l'impact des changements du climat des années à venir sur les rendements de maïs et de mil, et ainsi évalué les options d'adaptation à ce changement. Les principaux résultats indiquent qu'au Mali, la température augmentera au cours de la période 2040-2069 dans le temps et cette augmentation sera plus forte avec le scénario rcp8.5. Dans l'ensemble la tendance de la pluviométrie annuelle varie peu. Les pertes de rendements de maïs seraient de 45% et 47% respectivement pour les scénarios rcp4.5 et rcp8.5. L'application des doses recommandées d'engrais minéraux ne permettrait pas de compenser l'impact du changement climatique mais elle réduirait significativement les pertes de rendement. Pour le mil, la perte de rendement est de 16% et 14% respectivement pour les scénarios de rcp4.5 et rcp8.5. Si les doses d'engrais recommandées sont appliquées, ces pertes de rendement sont inversées dans les deux scénarios climatiques. Cette étude montre que faire face à la variabilité du climat et au changement climatique peut être possible: les pertes de rendement dues aux variations climatiques peuvent être compensées avec un choix adéquat des cultures et variétés, ainsi que l'amélioration des pratiques culturales (semis et fertilisation).

## Résumé

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## Acknowledgements

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### **Curriculum Vitae**



Bouba Traore was born on the 26th of June 1977 in San, Mali. He attended Ecole Fondamentale Baboudioni A in San for primary and secondary education before proceeding for high school education in the Lycee de Markala from 1994-1997. In 1998, he got admitted into Faculte des Sciences et Techniques de Bamako and Institut Polytechnique Rural de Formation et de Recherche Appliquée de Katibougou where he achieved a Bachelor of

Agricultural Engineer which he completed in December 2002.

In 2003, he joined the Institute D'Economie Rurale (IER) as junior researcher at the department of cotton. He completed a MSc study at Montpellier SupAgro in 2007 in agronomy and cropping system analysis in France.

He later got employed as civil servant for the Malian Ministry of Agriculture in 2008 and was appointed as research assistant at N'Tarla agricultural research station.

He is involved in developing research proposal on cotton cropping system, soil fertility management in relation with farmer's practices. He was in charge of the project COT4 based on research of alternative cropping systems for sustainable cotton production in Mali. He also worked within an interdisciplinary research team focusing on soil fertility and water management strategy aiming at improving smallholder's livelihoods in Mali. In 2009, he was admitted as PhD student at Plant Production System department of Wageningen University to conduct a research on Climate change, climate variability and adaptation options in smallholder cropping systems of Sudano - Sahel region in West Africa. Bouba Traore is married to Massiriba Kone and has got two beautiful daughters called Kinssa and Kadidia. He can be contacted on [boubasiditraore@yahoo.fr](mailto:boubasiditraore@yahoo.fr), [boubasiditraore@gmail.com](mailto:boubasiditraore@gmail.com)

### List of publications

#### Peers reviewed journal articles

**Traore, B.**, van Wijk, M.T., Descheemaeker, K., Corbeels, M., Rufino, M.C. and Giller, K.E., 2014. Evaluation of climate adaptation options for Sudano-Sahelian cropping systems. *Field Crops Research*, 156: 63-75.

**Traore, B.**, Corbeels, M., van Wijk, M.T., Rufino, M.C. and Giller, K.E., 2013. Effects of climate variability and climate change on crop production in southern Mali. *European Journal of Agronomy*, 49: 115-125.

**Traore, B.**, vanWijk, M.T., Descheemaeker, K., Corbeels, M., Rufino, M.C. and Giller, K.E., Farmer's perceptions on climate change and on agricultural adaptation strategies in southern Mali. Under review in *experimental agriculture*.

**Traore, B.**, Descheemaeker, K., van Wijk, M.T., Corbeels, M., Supit, I. and Giller, K.E., Impact of future climate change on maize and millet production and adaptation options for cropping systems in the Sudano-Sahelian zone of West Africa. To be submitted in *climatic change journal*

Rapidel, B., **Traore, B.**, Sissoko, F., Lançon, J. and Wery, J., 2009. Experiment-based prototyping to design and assess cotton management systems in West Africa. *Agronomy for Sustainable development*, 29(4): 545-556.

Barrabe, A., Rapidel, B., Sissoko, F., **Traore, B.** and Wery, J., 2007. Elaboration and test of a decision rule for the application of mepiquat chloride on cotton in Mali. *European Journal of Agronomy* 27: 197 - 204.

Rapidel, B., Defèche, C., **Traore, B.**, Lancon, J. and Wery, J., 2006. In-field development of a conceptual crop functioning and management model: A case study on cotton in southern Mali. *European journal of Agronomy*, 24: 304-315.

**Traore, B.**, Rapidel, B., Sissoko, F. and Doucouré, C.T., 2005. Evolution des techniques culturales en zone cotonnière entre 1997 et 2002. *Les Cahiers de l'Economie Rurale*, 2: 21-28.

#### International conference and workshop proceeding

**Traore, B.**, Descheemaeker, K., van Wijk, M. T., Corbeels, M., Rufino, M. C., Giller, K. E., 2013. Climate adaptation options for Sahelian cropping systems. In: K.E. Giller and M. van Hittersum (Editors), *First International Conference on Global Food Security*, Noordwijkerhout, The Netherlands.

**Traore, B.**, Rufino, M.C., Corbeels, M., Van Wijk, M.T. and Giller, K.E., 2010. Exploratory analysis of climate parameters for decision support in crop production. In: J. Wery, I. Shili -Thoizi and A. Perrin (Editors), *Agro2010 the XI ESA Congress, Symposium 4 ``Innovation and decision support in agriculture`` August 29<sup>th</sup> - September 3<sup>rd</sup>, 2010*, Montpellier France, pp. 125-126.

**Traore, B.**, Louhichi K. and Rapidel, B., 2009. A bio-economic model to analyse the performance of the cotton sector in Mali pp. 276-277. In: M.K. Van Ittersum, J. Wolf & H.H. Van Laar (Editor), AgSAP Conference 2009, Egmond aan Zee, The Netherlands 10-12 March, pp. 560

**Traore, B.**, Rapidel, B., Louhichi, K., Barbier, B. and Belhouchette, H., 2007. A farm based model to test the suitability of new cotton cropping systems with farmers in Mali: Farming Systems Design 2007, Int. Symposium on Methodologies on Integrated Analysis on Farm Production Systems, M. Donatelli, J. Hatfield, A. Rizzoli Eds., Catania (Italy), 10-12 September 2007, book 2 – Field-farm scale design and improvement, page 17-18.

Rapidel, B., Sissoko, F., **Traore, B.**, Lançon, J. and Wery, J., 2005. Diversification des itinéraires techniques recommandés pour la culture cotonnière au Mali. In: M. Adégnika, F. Okry and B. Ouédraogo (Editors), Conférence Coton de l'Afrique de l'Ouest et du Centre. CORAF-INRAB-IFDC, Cotonou, pp. 191-194.

**Traore, B.**, Autfray, P., Rapidel, B. and Sissoko, F., 2005. Création participative des systèmes de cultures à base de plantes de couvertures. Poster. 3eme congrès mondial sur l'agriculture de conservation. Nairobi Kenya 2005., 3eme congrès mondial sur l'agriculture de conservation, Nairobi Kenya.

**Traore, B.**, Rapidel, B., Sissoko, F. and Doucouré, C.T., 2005. Evolution des techniques culturales en zone cotonnière entre 1997 et 2002. . In: M. Adégnika, F. Okry and B. Ouédraogo (Editors), Conférence Coton de l'Afrique de l'Ouest et du Centre. CORAF-INRAB-IFDC, Cotonou, pp. 201-203.

### **Theses**

**Traore, B.**, 2002. Diagnostique agronomique de l'impact des pratiques paysannes sur le rendement du coton: Village de Katogo Mémoire de fin d'études, cycle ingénieur agronome Thesis, IPR/IFRA Katibougou, 43 pp.

**Traore, B.**, 2007. Utilisation d'un modèle de simulation du fonctionnement de l'exploitation agricole comme interface de dialogue entre la recherche agronomique et les agriculteurs concernant l'adoption de nouvelles options techniques de culture. Master en Agronomie et Agroalimentaire, Option: Agronomie et Systèmes de Culture Intégrés en Zone Tropicale Thesis, SupAgro, 34 pp.

### PE&RC Training and Education Statement

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)



#### Review of literature (6 ECTS)

- Climate change, climate variability and adaptation options in smallholder cropping systems of Sudano – Sahel region in West Africa (2014)

#### Writing of project proposal (4.5 ECTS)

- Assessing the effect of climate change on agricultural productivity and on farmers' livelihoods in Southern Mali

#### Post-graduate courses (6.9 ECTS)

- Analysing farming systems and rural livelihoods in a changing world: vulnerability and adaptation; WGS/University of Zimbabwe (2008)
- WIAS Course tropical farming systems with livestock; WIAS (2013)
- Photosynthesis, climate and change; PE&RC (2013)
- Mixed linear models; PE&RC (2013)

#### Deficiency, refresh, brush-up courses (3 ECTS)

- Systems analysis, simulation and systems management (2009)
- Connaissance theorique et pratique en Biometrie et des logiciels d'analyse et traitement des donnees en agronomie (2010)

#### Competence strengthening / skills courses (3.1 ECTS)

- Working with dynamic models for agriculture; SupAgro (2010)
- Formation a la communication scientifiques et professionnelle; CIRAD (2010)
- Mobilising your – scientific – network; WGS (2013)
- 

#### PE&RC Annual meetings, seminars and the PE&RC weekend (1.2 ECTS)

- PE&RC Weekend (2013)
- PE&RC Days: Biomimicry: unlocking nature's secrets (2013)

#### Discussion groups / local seminars / other scientific meetings (6.3 ECTS)

- Annual scientific meeting of IER; Mali (2009, 2010 and 2011)
- Fertilité, fertilisation et management des sols sous semis direct sur couverture vegetale; Mali (2011)
- Sustainable Intensification of Agricultural Systems; Wageningen (2013)

#### International symposia, workshops and conferences (8.9 ECTS)

- Participatory Action Research (PAR) in Wedza Smallholder Farming Area workshop 1 and 2; Zimbabwe (2009 and 2010)
- International conference XIESA Congress Agro2010; poster presentation; Montpellier (2010)
- Modelling of cereal-livestock-trees interactions using APSIM model (2012)
- First International Global Food Security conference; poster presentation (2013)
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